

WHIM Emission in the Space UV: the Evolution of Galaxies and Their Circumgalactic Gas

- GALEX
- FIREBall (balloon)
- ISTOS (proposed SMEX)

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(Columbia University)

w/ C. Martin (Caltech), B. Milliard (LAM)
& S. Tuttle, G. Bryan (Columbia)

Cosmic Far Ultraviolet Background ~ 40 years ago

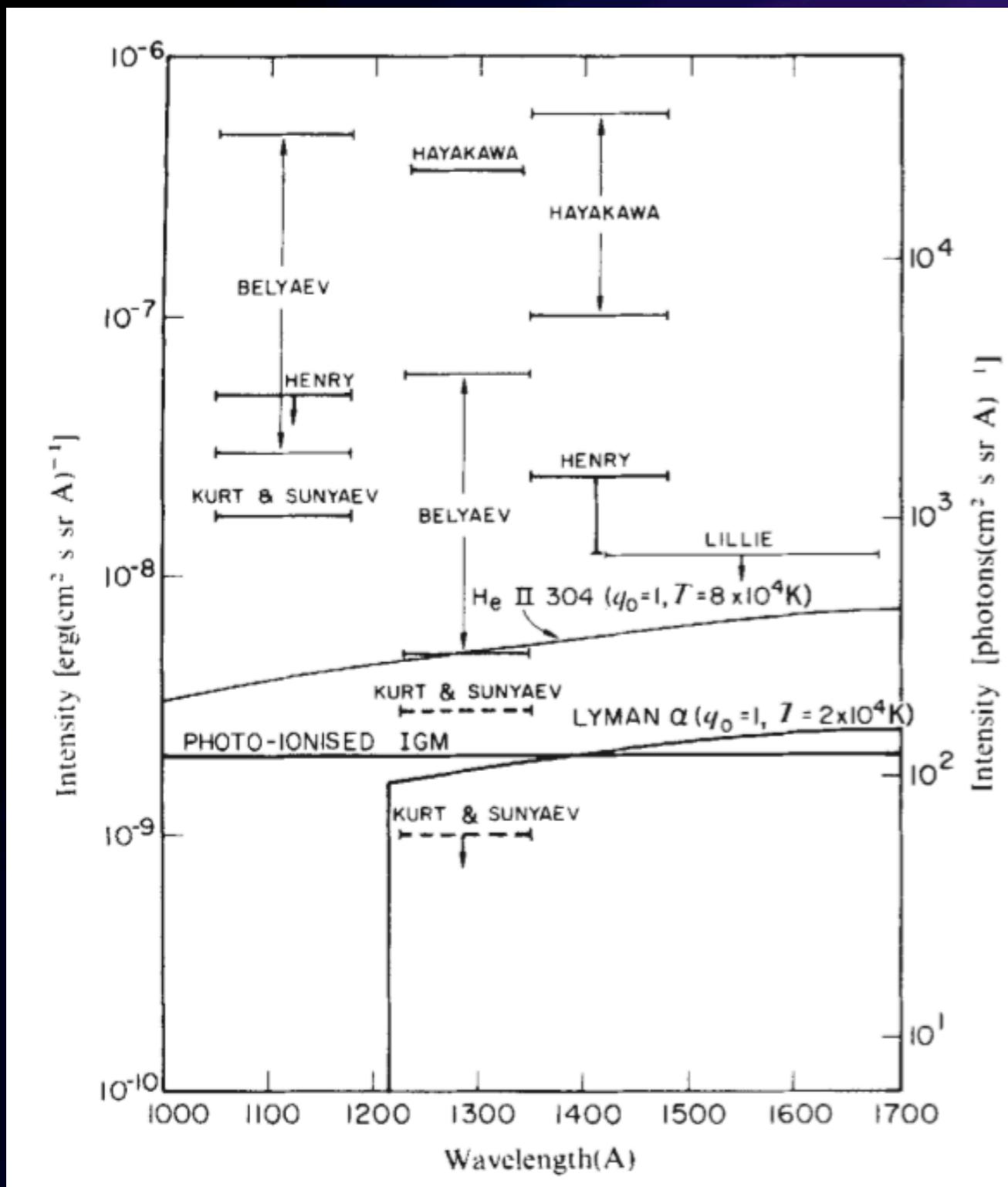
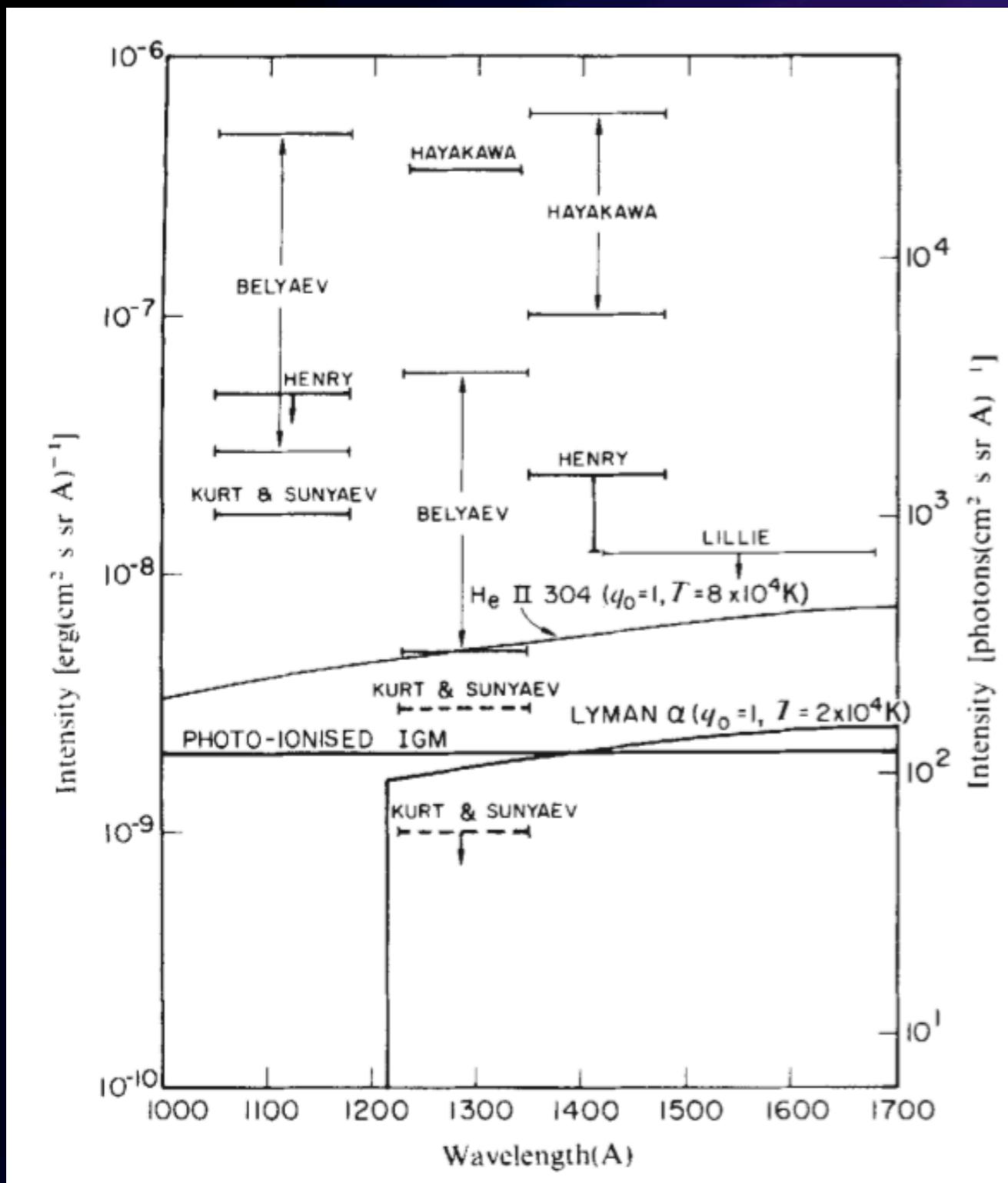


Fig. 1 Observed and predicted intensities of the diffuse far ultraviolet background. The measurements are discussed in the text. The lowest intensities, due to Kurt and Sunyaev, are contradicted by later results. The Lyman α flux from recombinations IGM with $q_0 = 1$ and $T = 2 \times 10^4$ K (assumed constant with Z) is shown. A similar flux due to He II 304 Å recombinations at large Z is also shown. Also presented is an estimate of the flux which is necessary to produce a sufficient degree of photoionisation in an IGM having the critical density. Local and Galactic components of diffuse light are probably weak enough at high latitude to allow detection of a cosmic flux of approx 10^{-9} erg (cm² s sr Å)⁻¹. A sensitivity at this level can be achieved with current instrumentation.

Models assume uniform critical density component
Davidson, Bowyer & Lampton, Nature (1974)

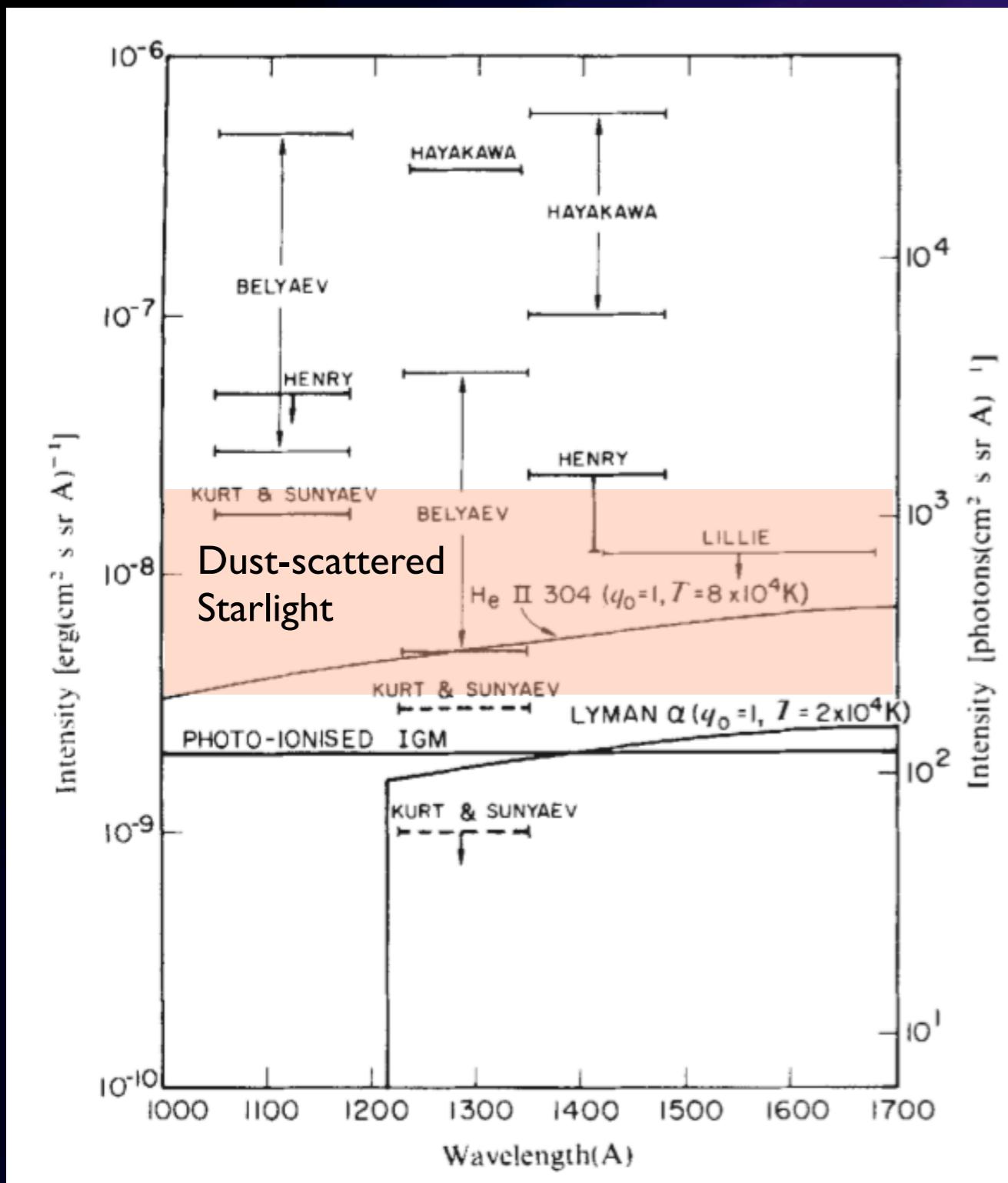
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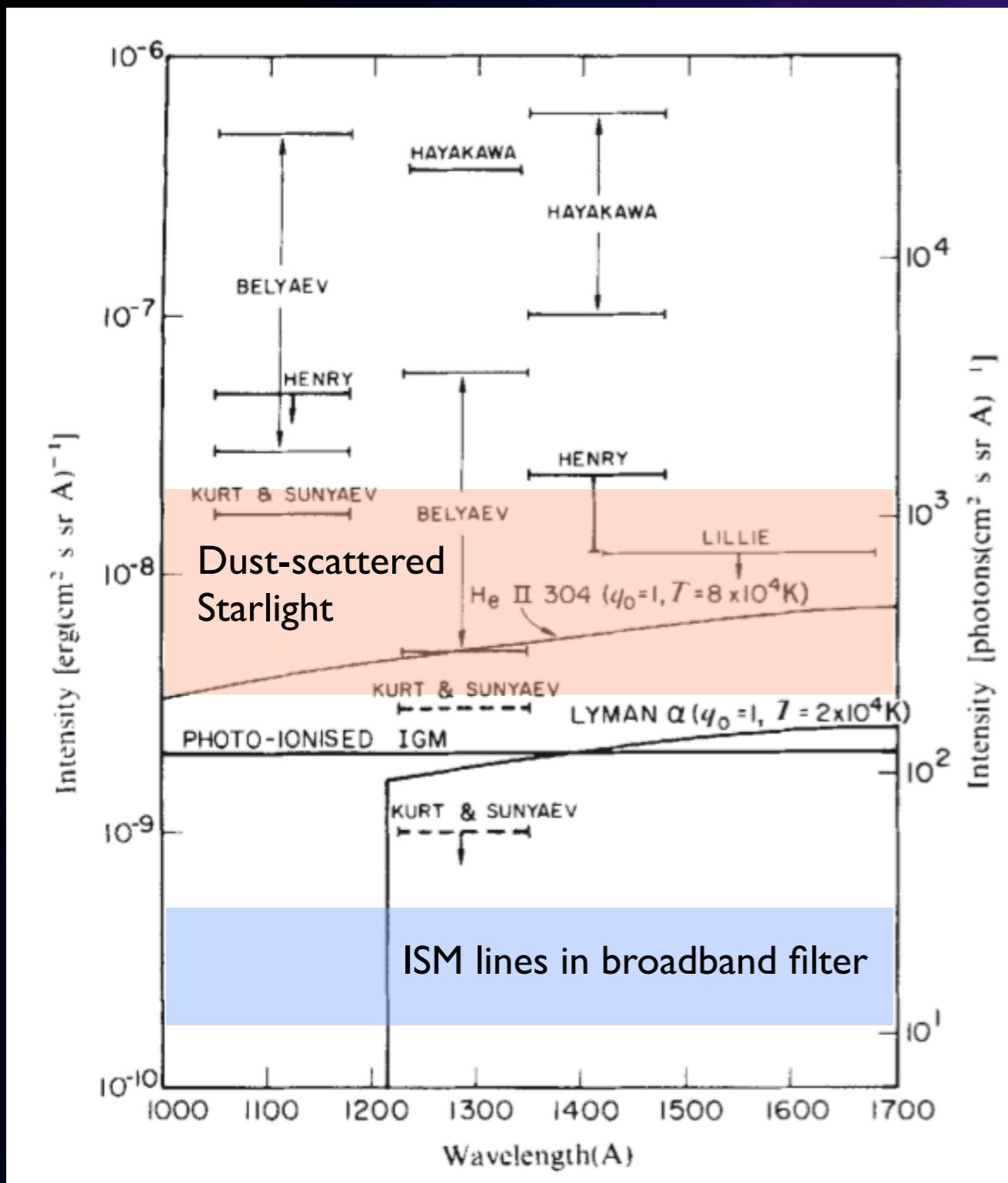
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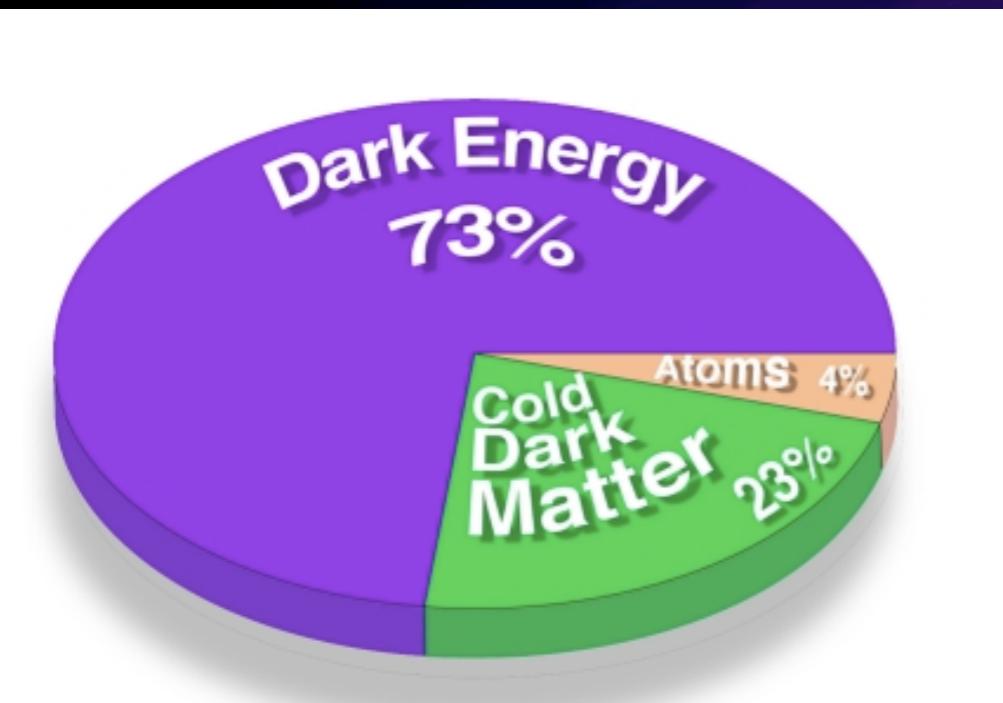


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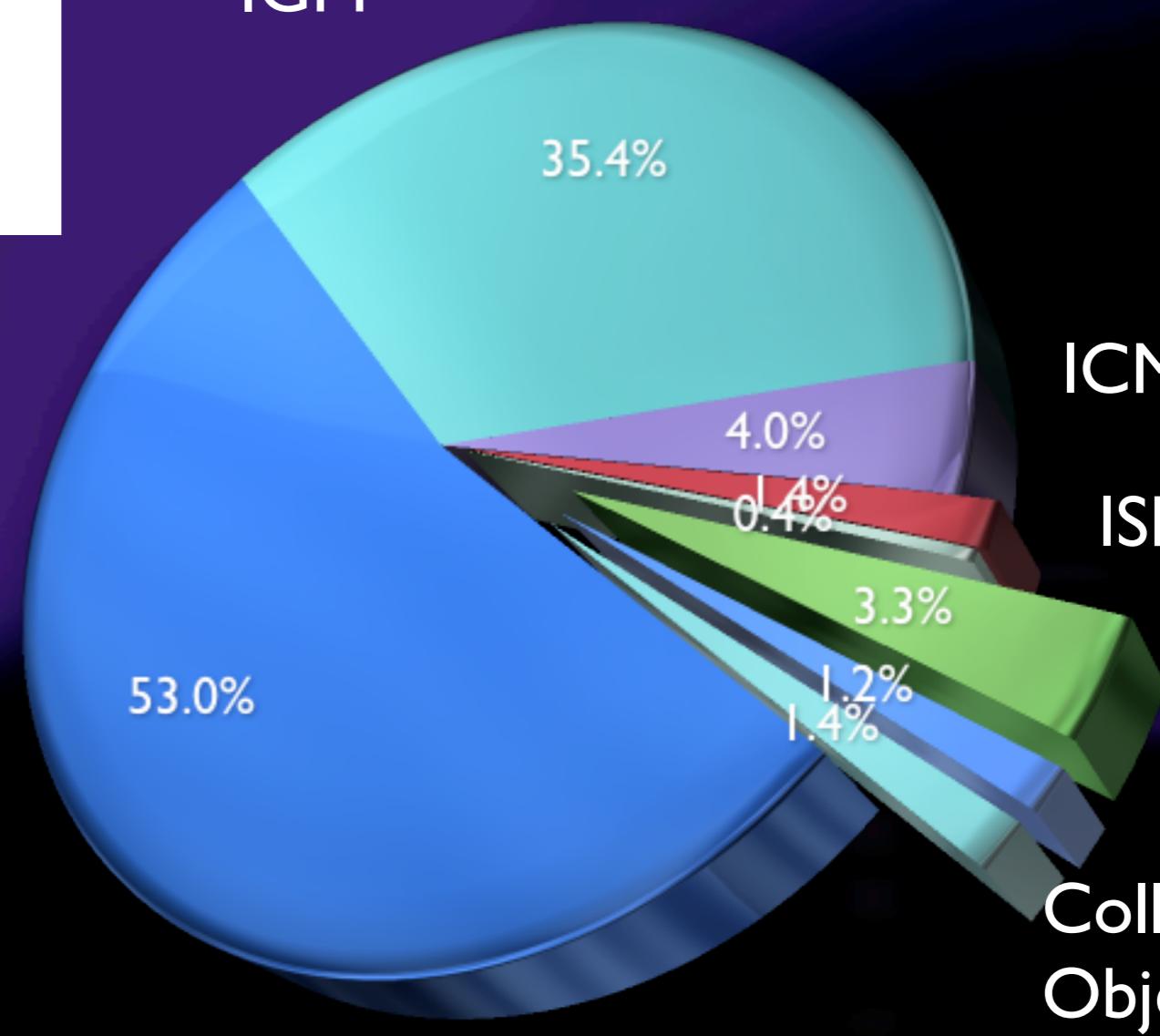
Precision Cosmology & the Baryon Inventory

e.g. Fukugita & Peebles (2004)



New Paradigm

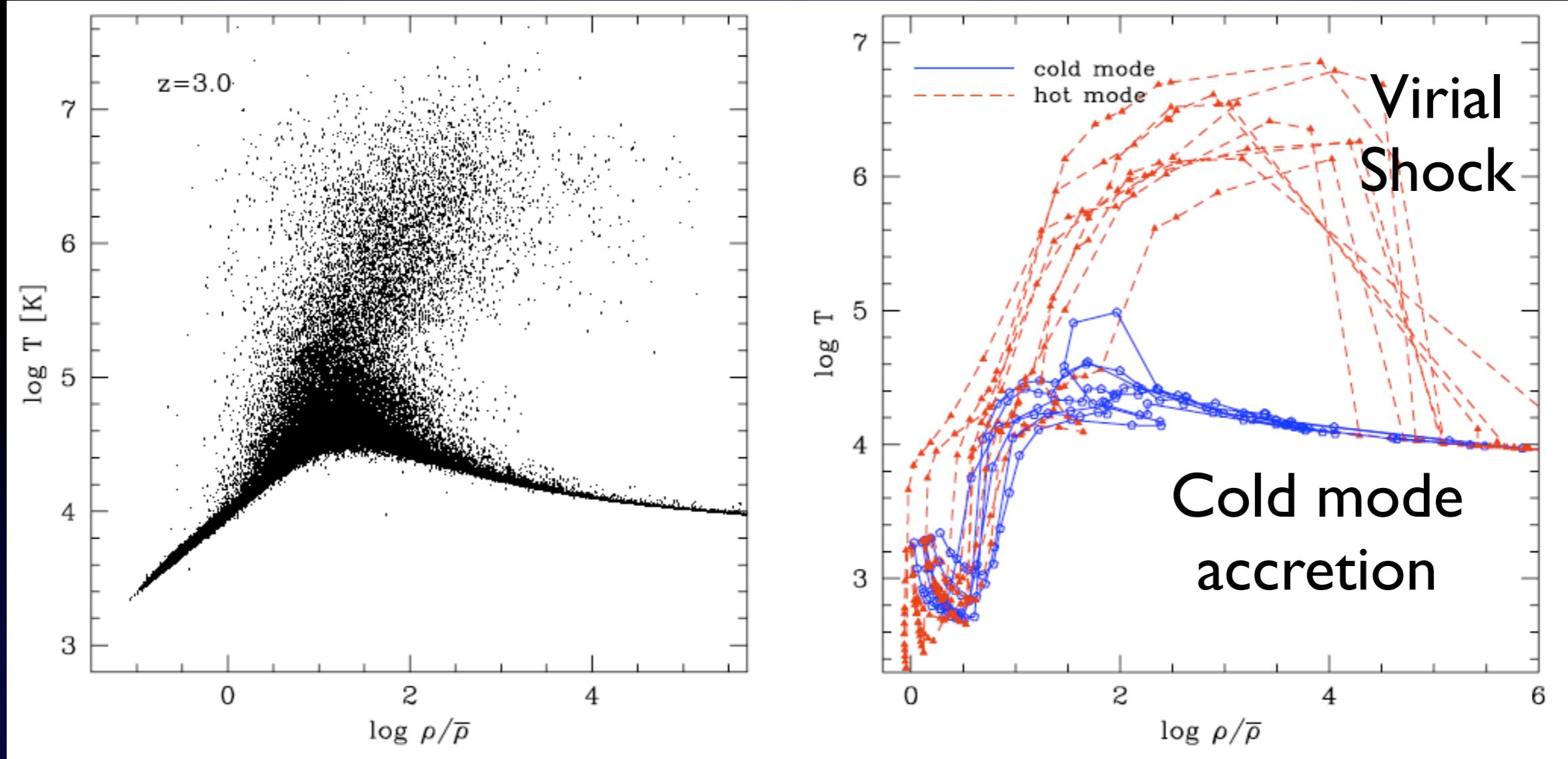
Diffuse
~ 94%



IGM/Galaxy Evolution Connection

“How Galaxies Get Their Gas” (e.g. Keres et al (2005))

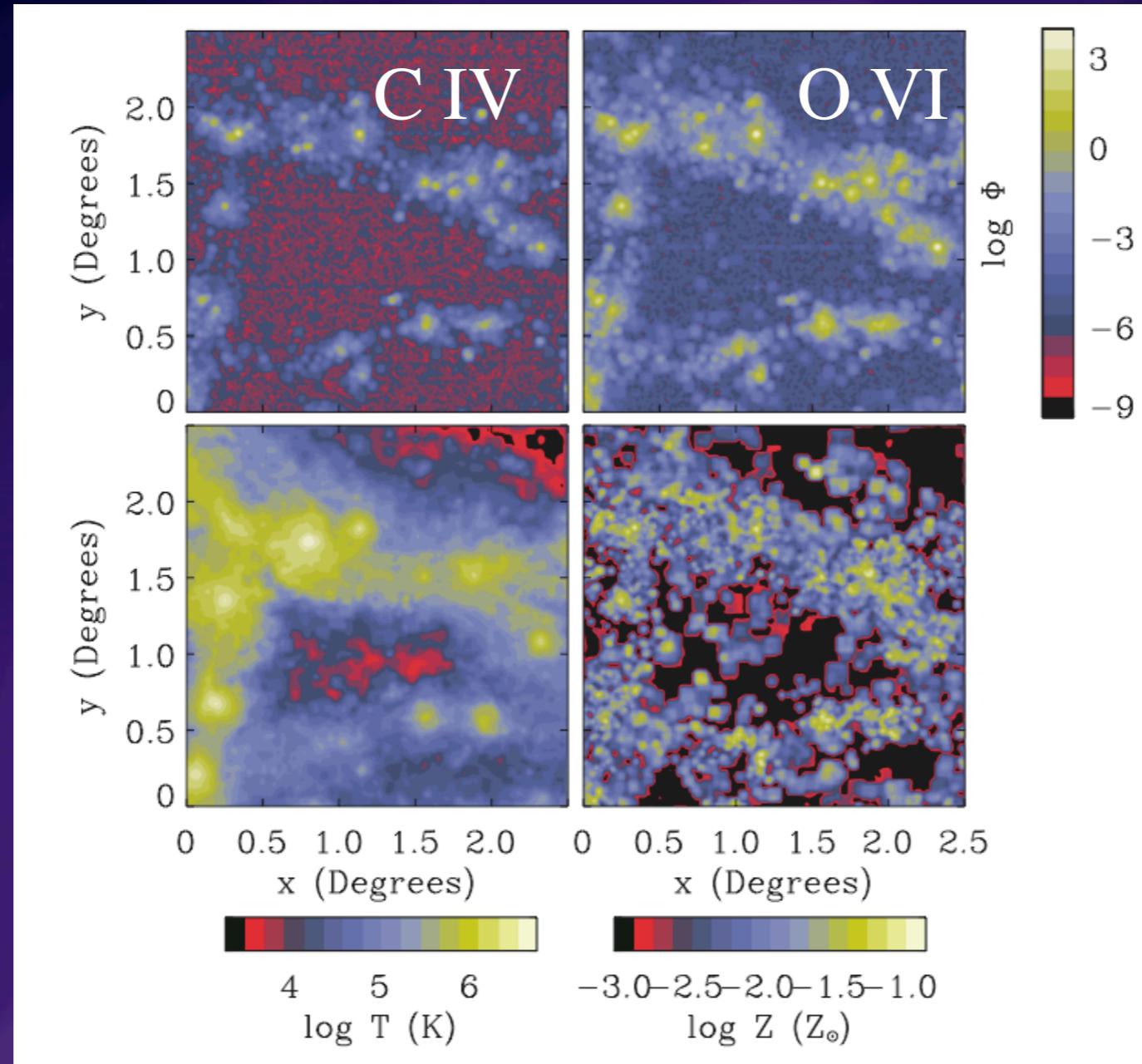
New Paradigm



Detailed Hydrodynamic Simulations of IGM+Galaxy Evolution e.g. Oppenheimer & Dave (2007), Furlanetto et al (2004)

64 Mpc/h box, 16M gas particles
Metallicity-boosted momentum driven winds

Detailed Hydrodynamic Simulations of IGM+Galaxy Evolution e.g. Oppenheimer & Dave (2007), Furlanetto et al (2004)





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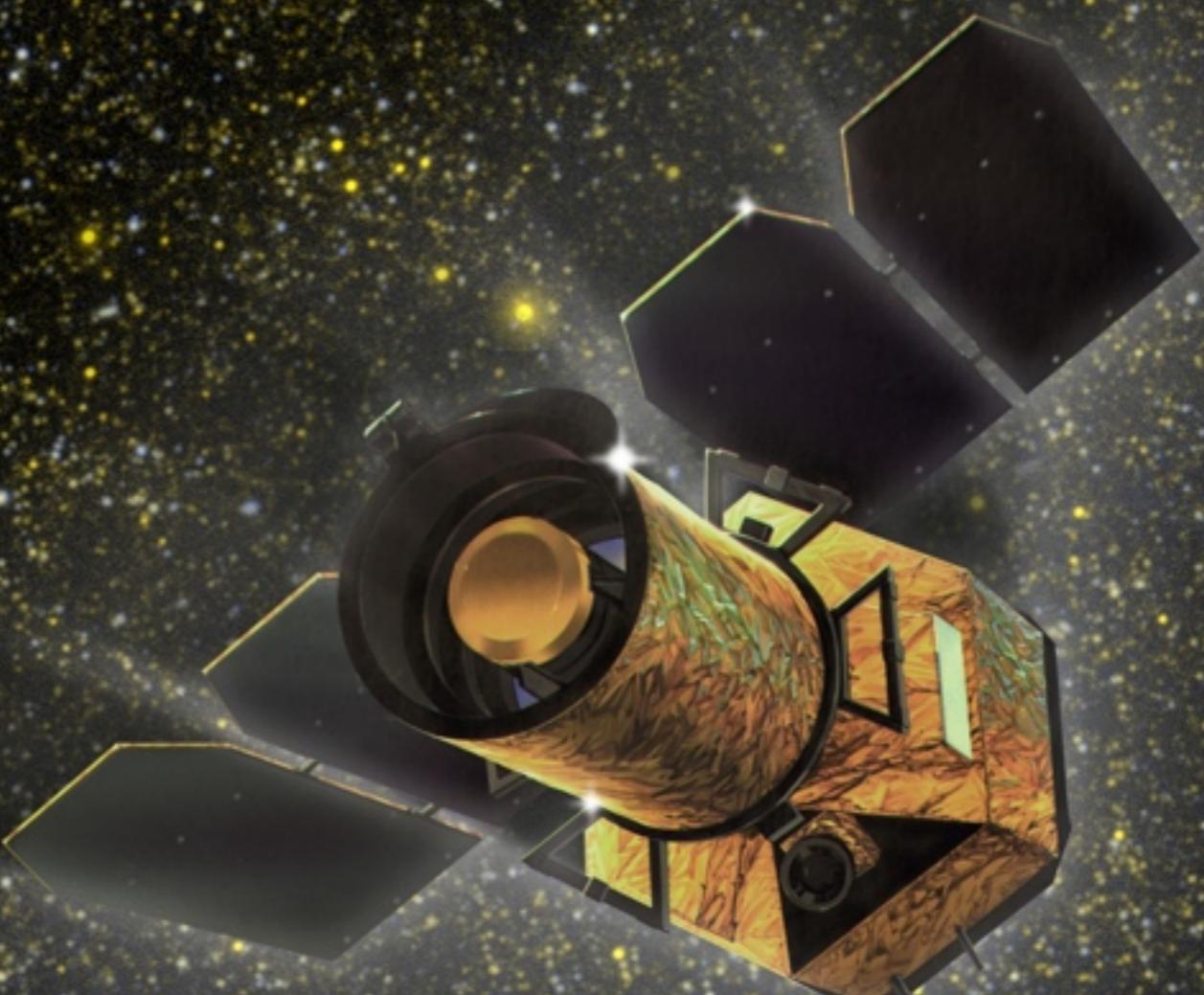
UCLA

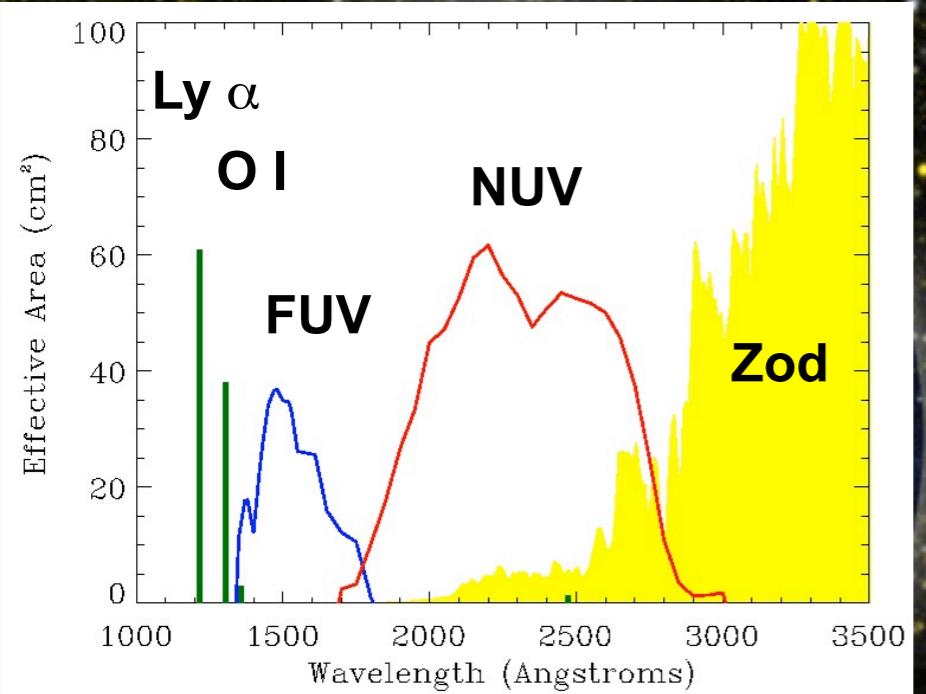


GALEX

Galaxy Evolution Explorer

Surveying the Ultraviolet Universe





GALEX

Galaxy Evolution Explorer

Surveying the Ultraviolet Universe

- Calibrate rest-frame UV as a SFR measure
- Measure Star Formation History ($0 < z < 1.5$)
- Determine drivers for Star Formation History
- Explore the UV Universe



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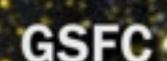
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GSFC

UCLA

The Dark UV Sky:

M83



The Dark UV Sky:

M83



The Dark UV Sky:

Mira



The Dark UV Sky:

Mira



The Dark UV Sky:

Mira



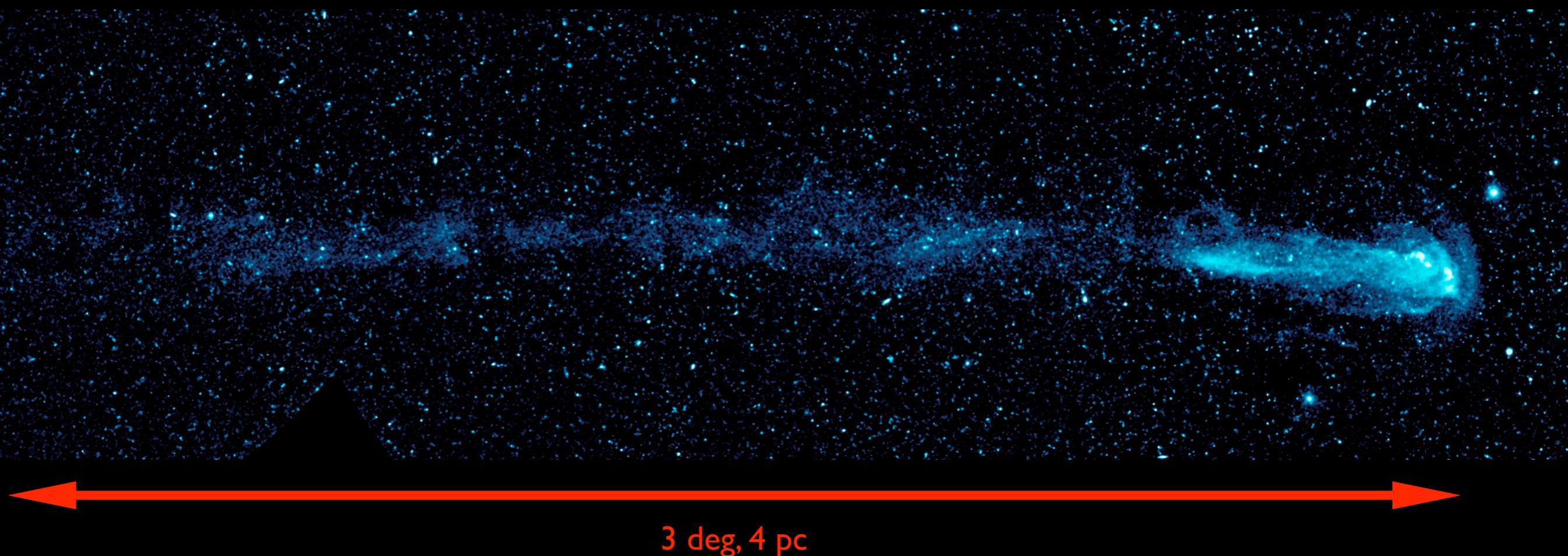
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Mira



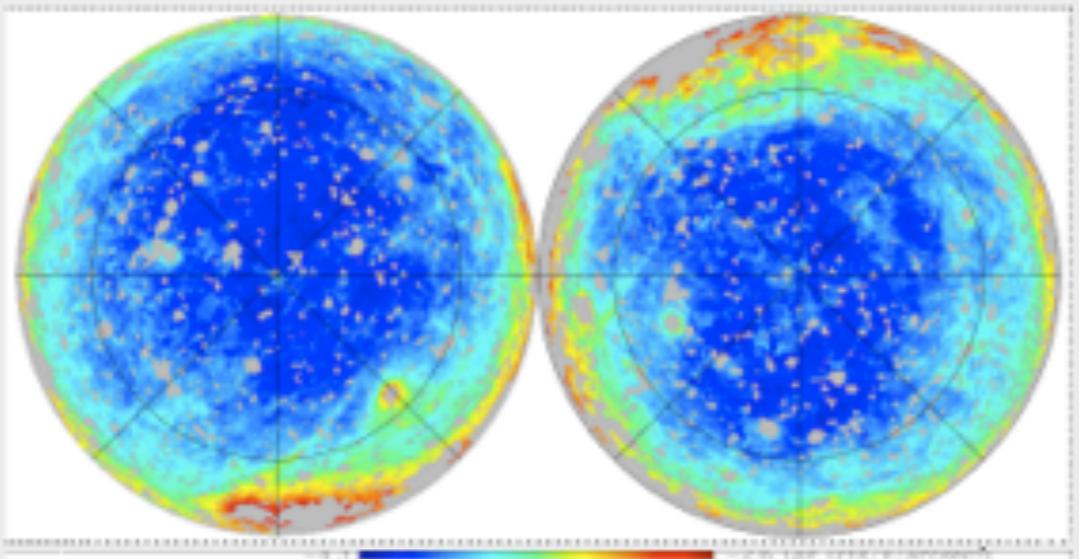
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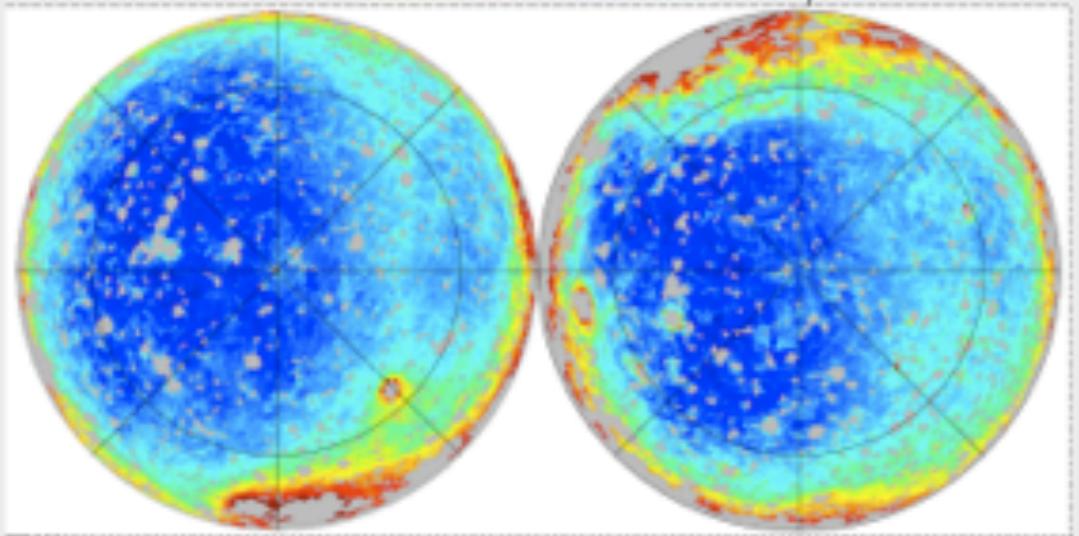


3 deg, 4 pc

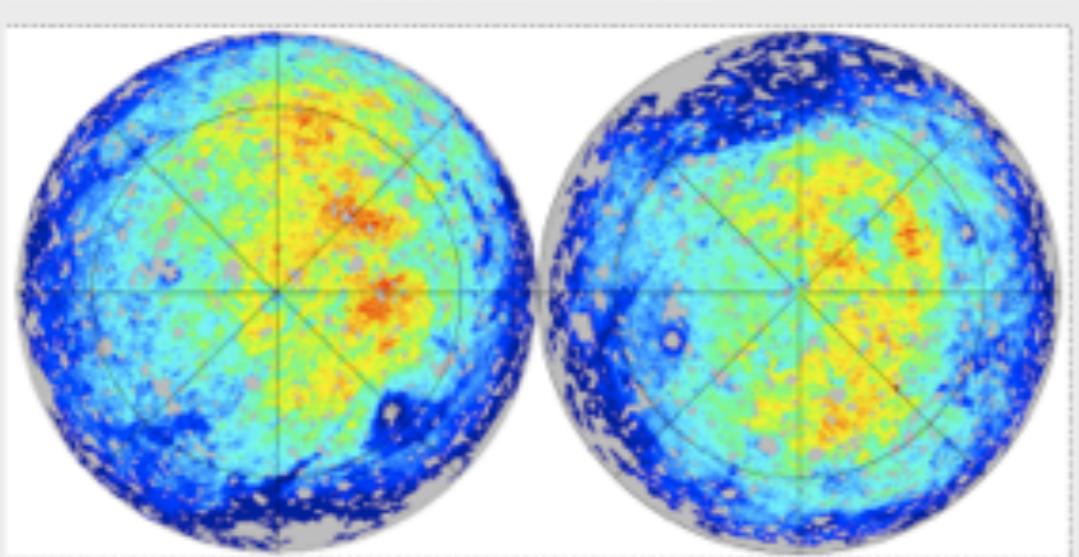
All-Sky Imaging Survey



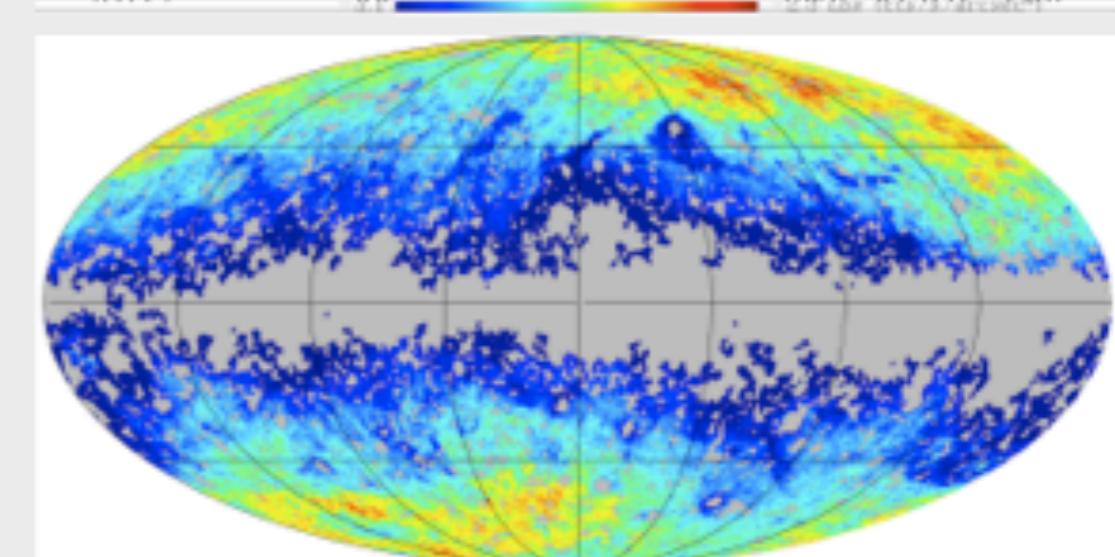
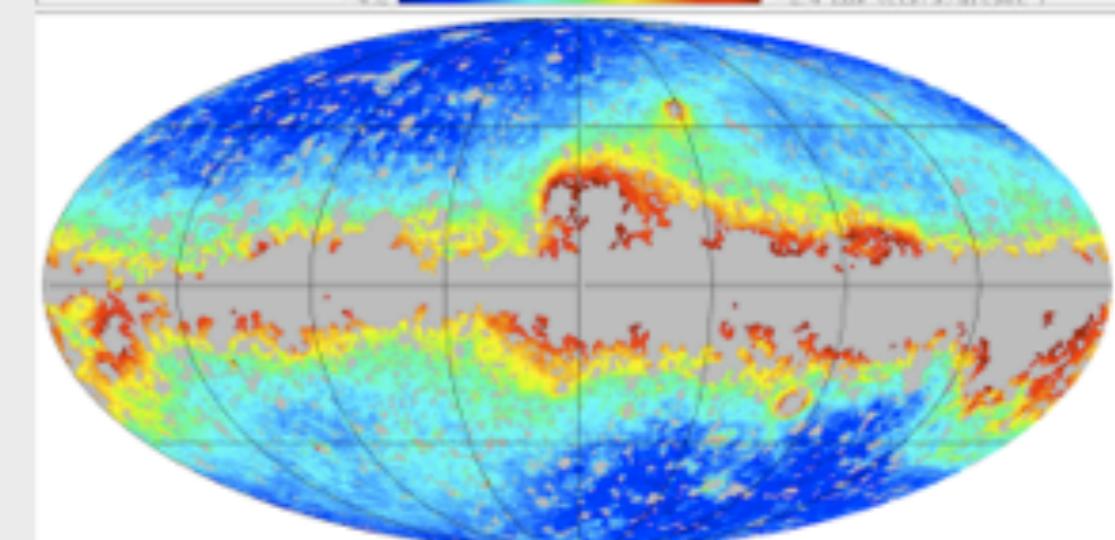
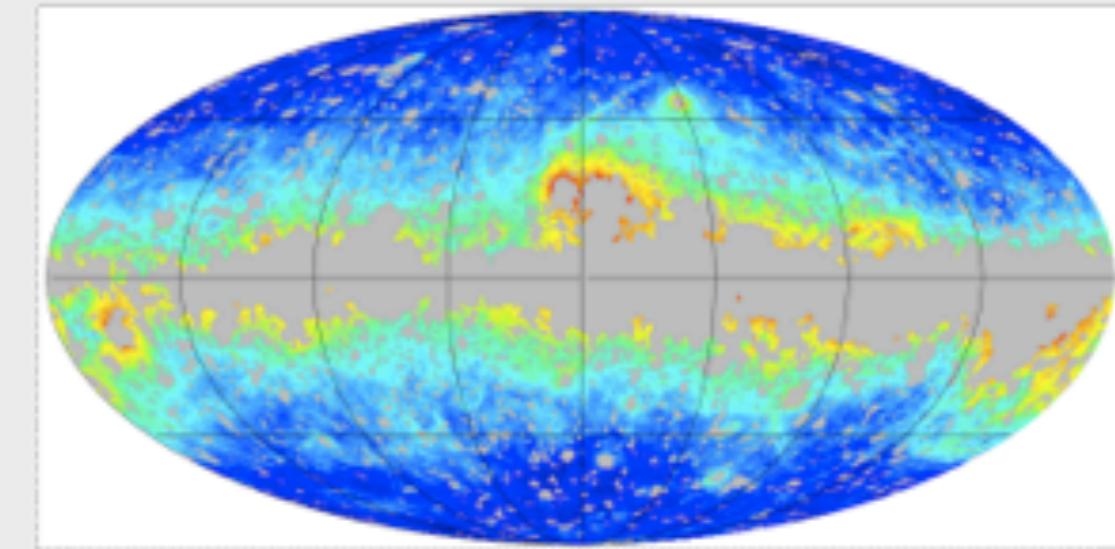
FUV



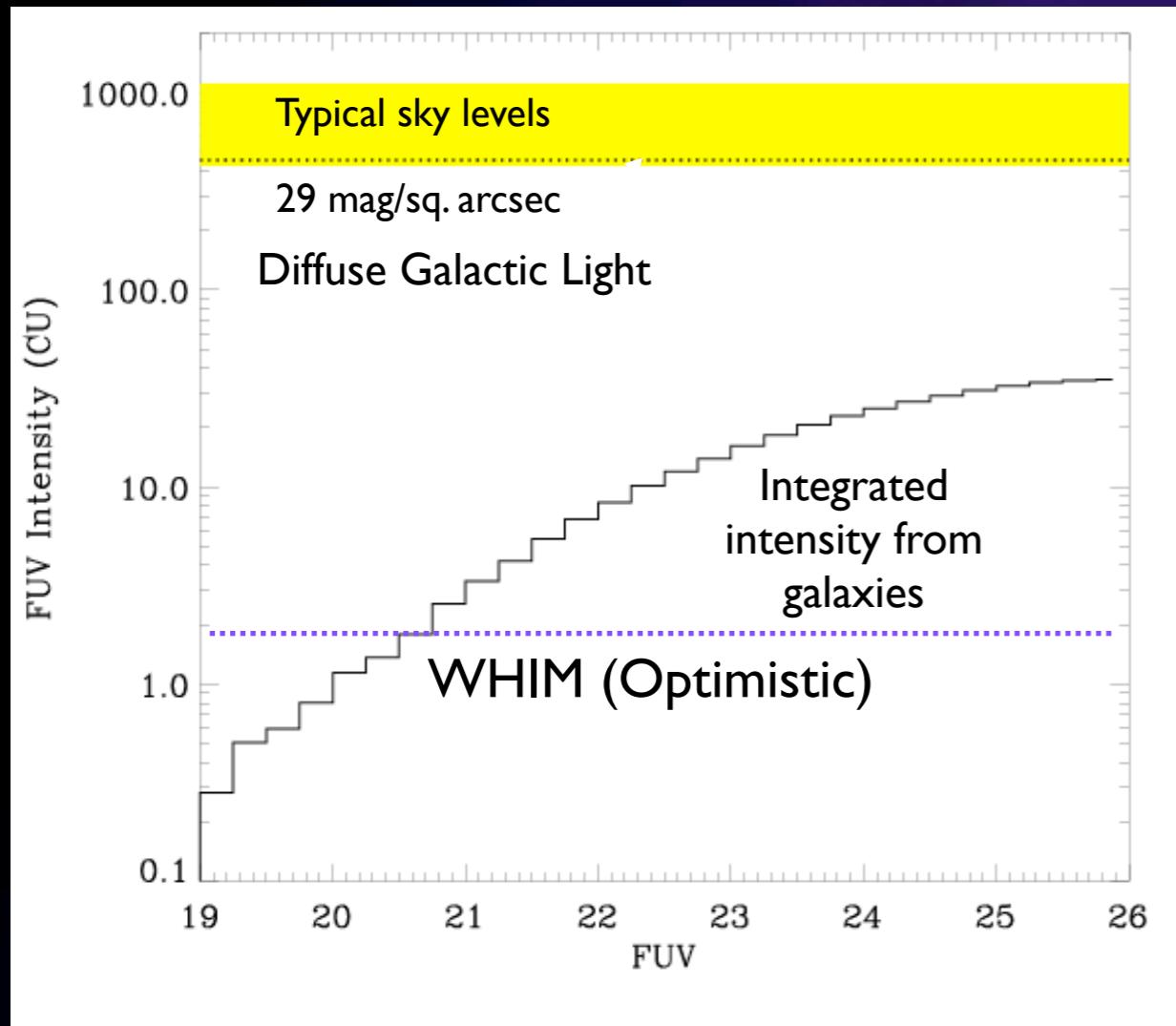
NUV



NUV/FUV

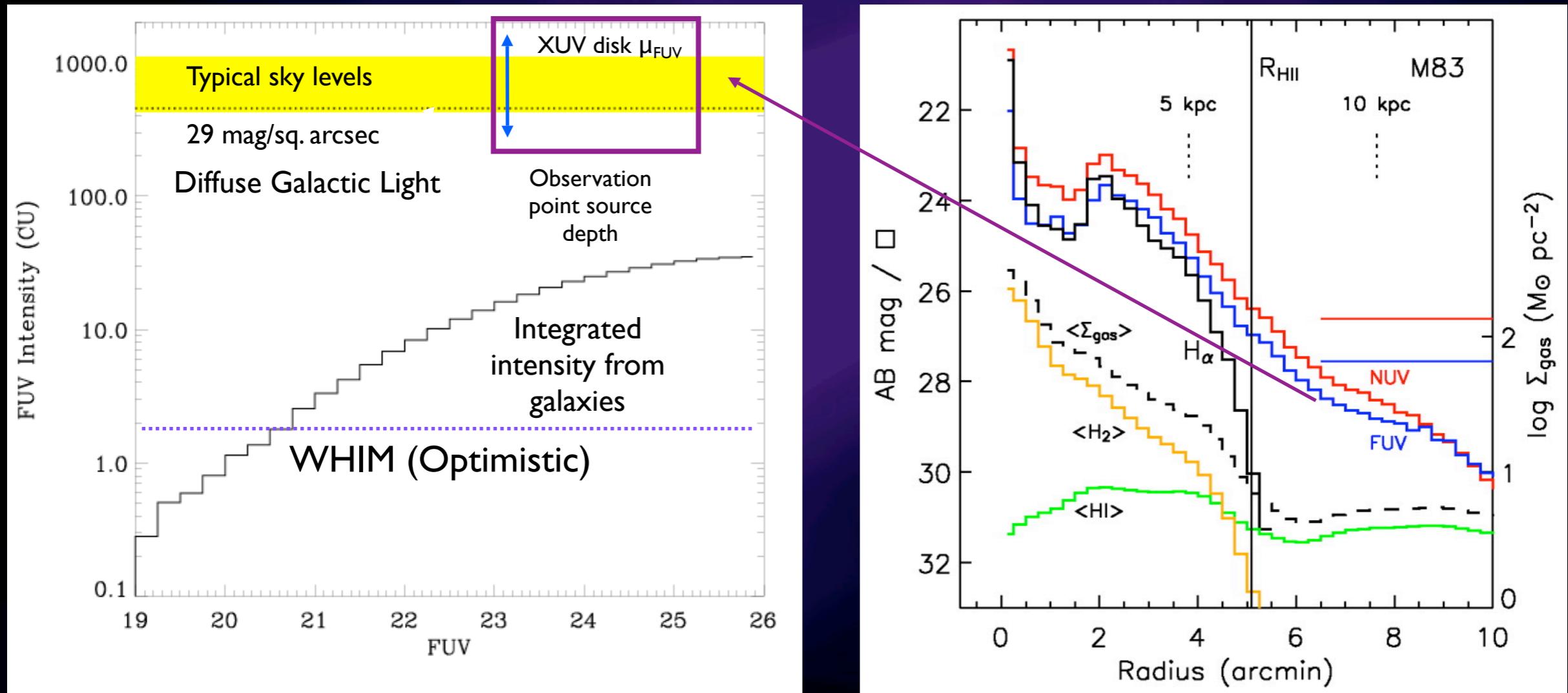


GALEX broadband sky background & integrated counts:



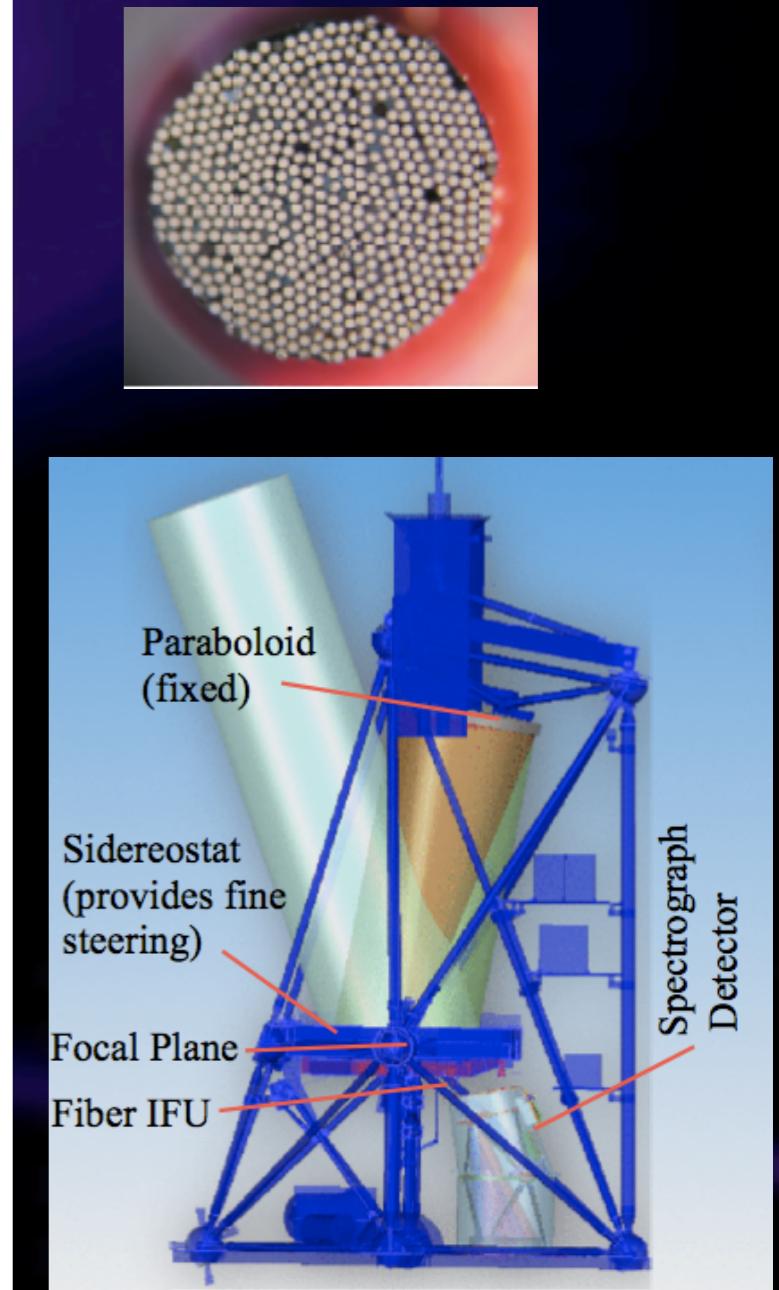
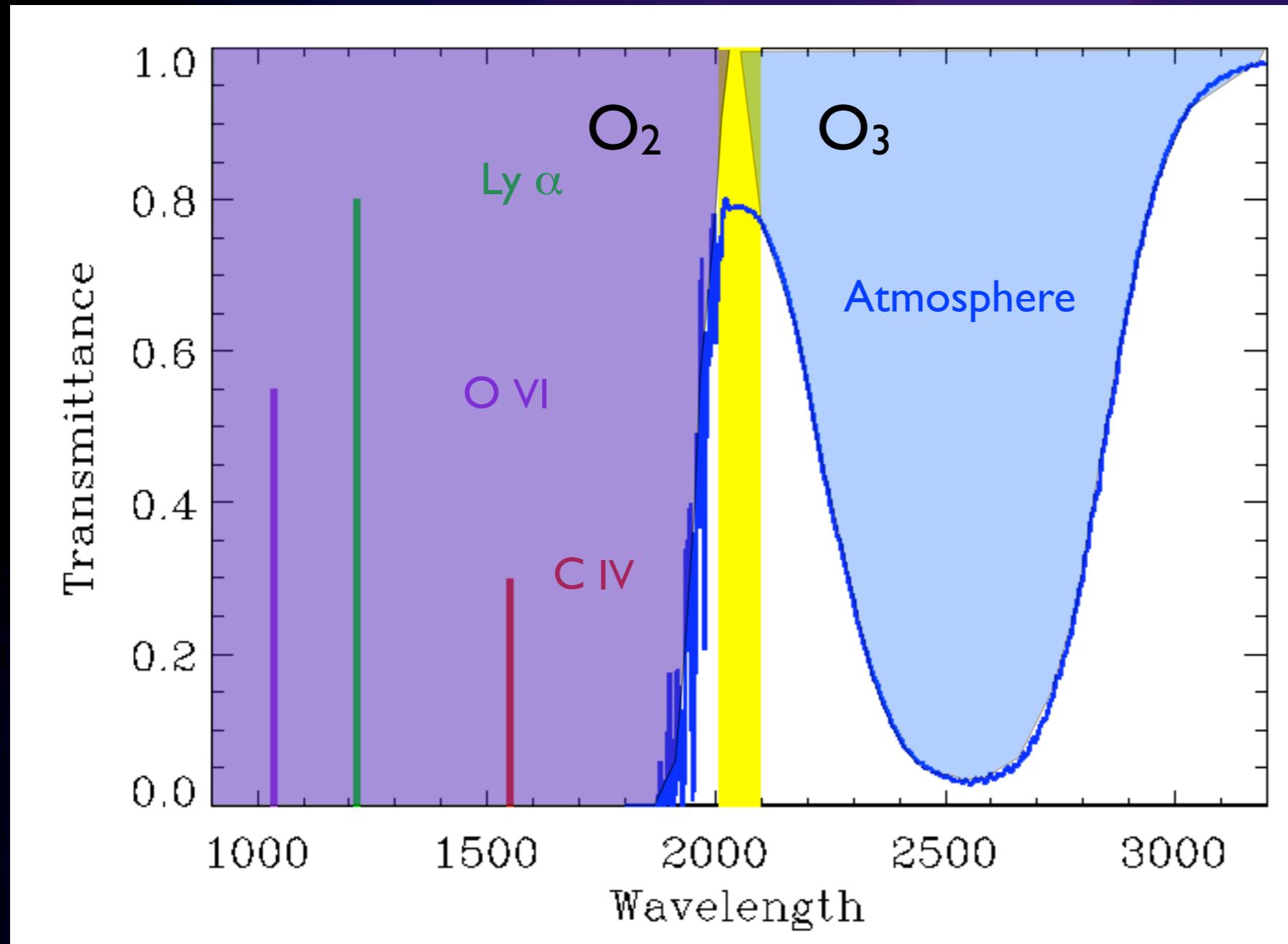
- GALEX resolves out nearly all of the point source background.
- UV background dominated by Galactic dust-scattered continuum (and zodiacal light in NUV)
- WHIM contribution to background in FUV band likely to be <1% Galactic signal
- May be accessible through stacking (e.g. galaxy clusters, luminous galaxies)

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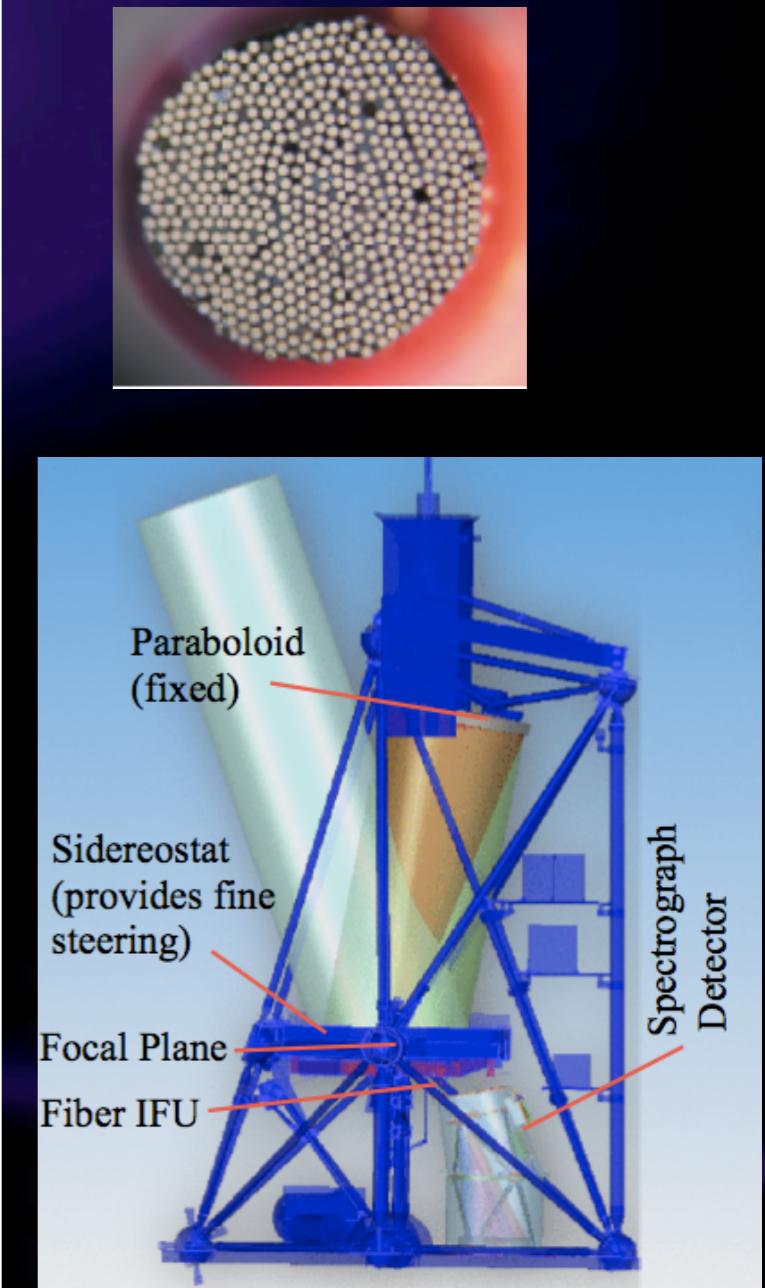
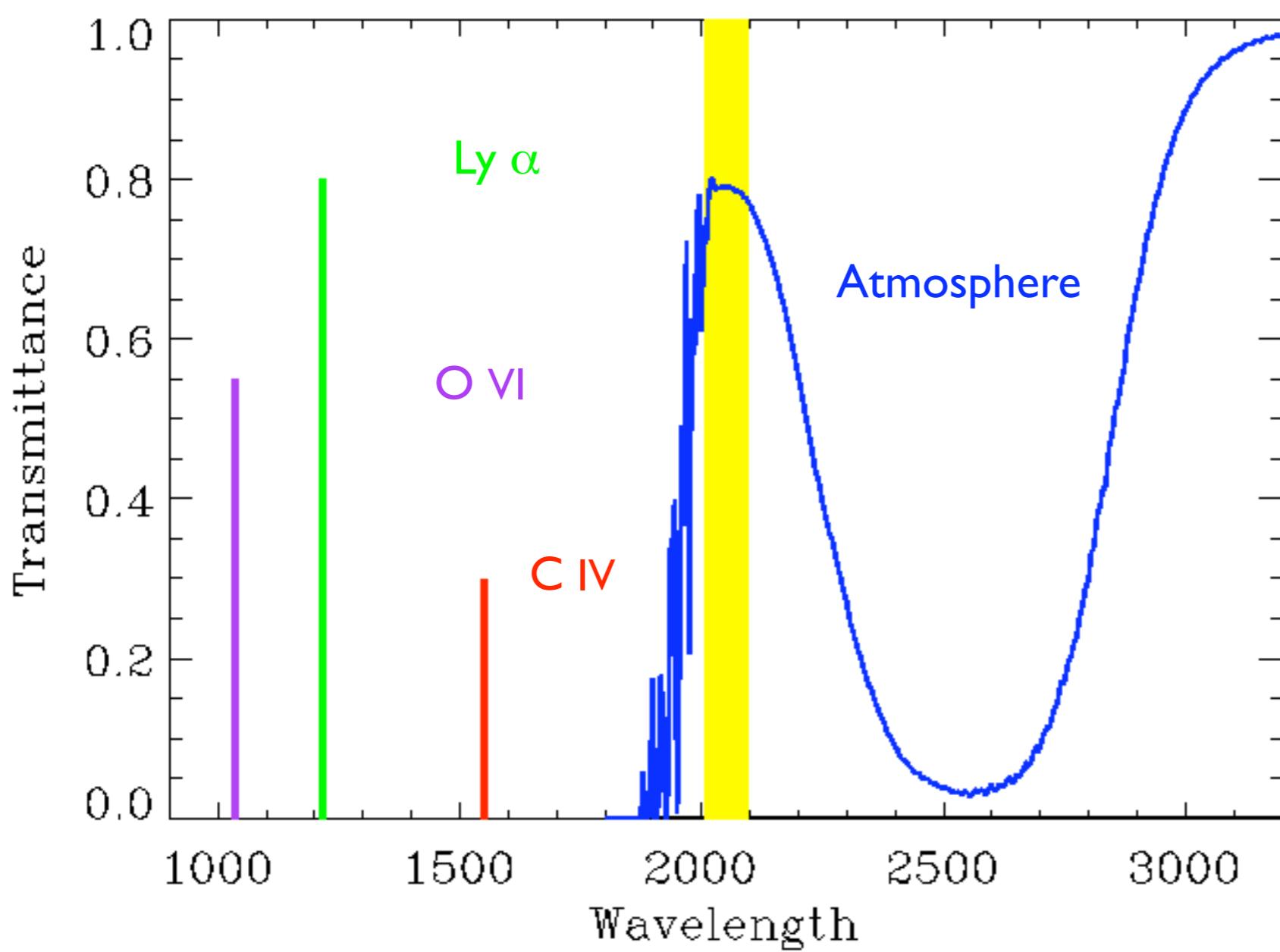
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Faint Intergalactic Redshifted Emission Balloon (FIREBall)



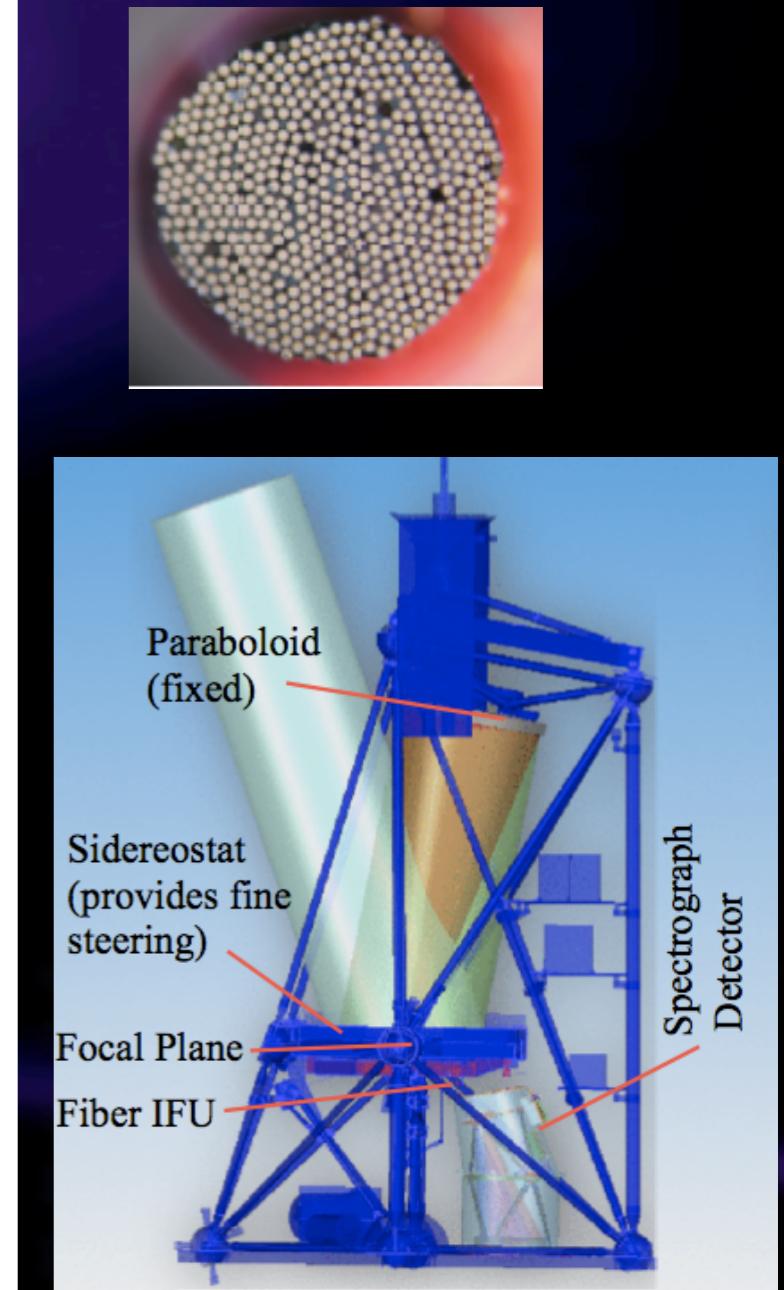
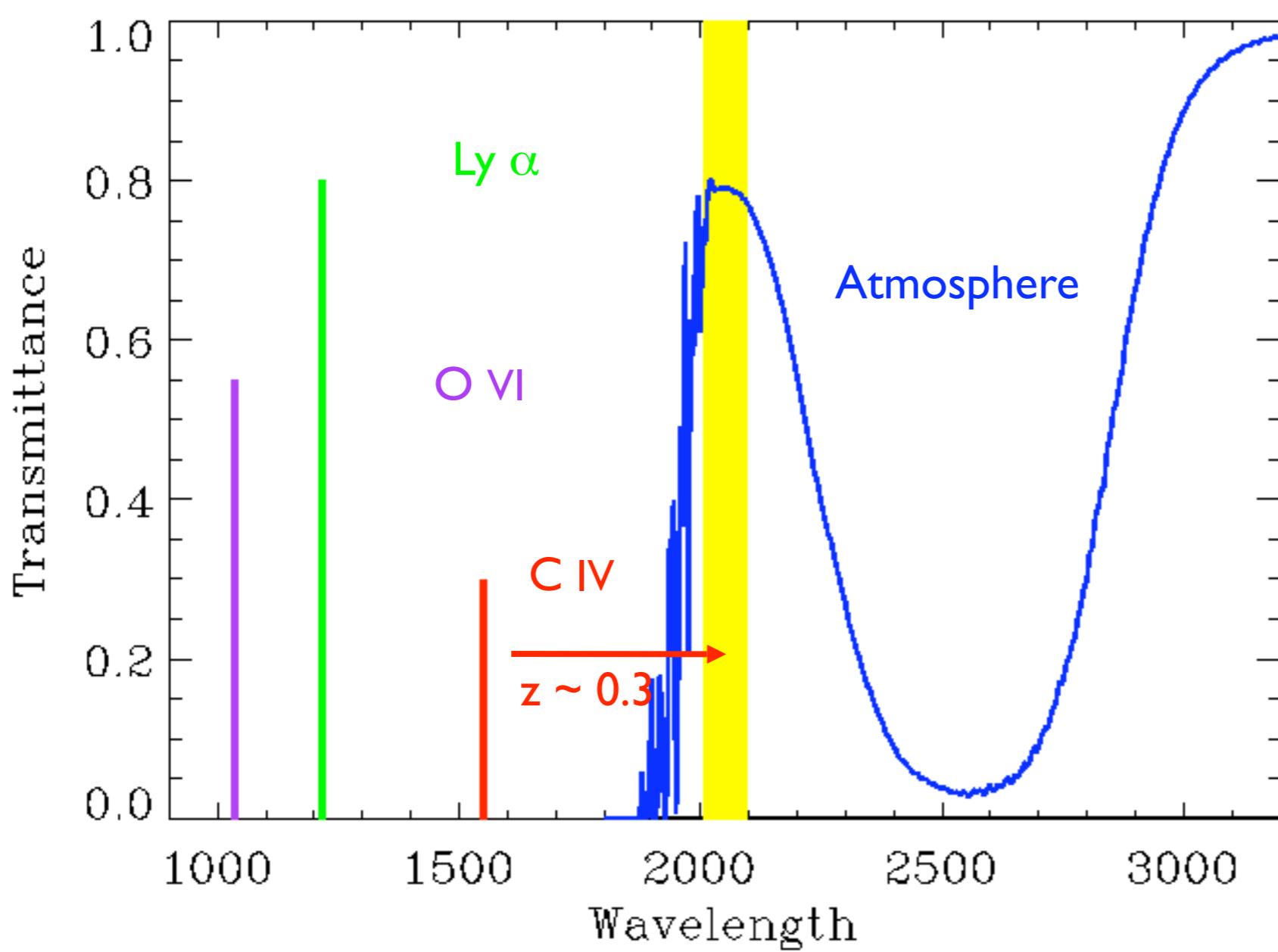
- 1 m Telescope, IFU 2-3' FOV, 10'' res., ~400 Fiber IFU, R~5000

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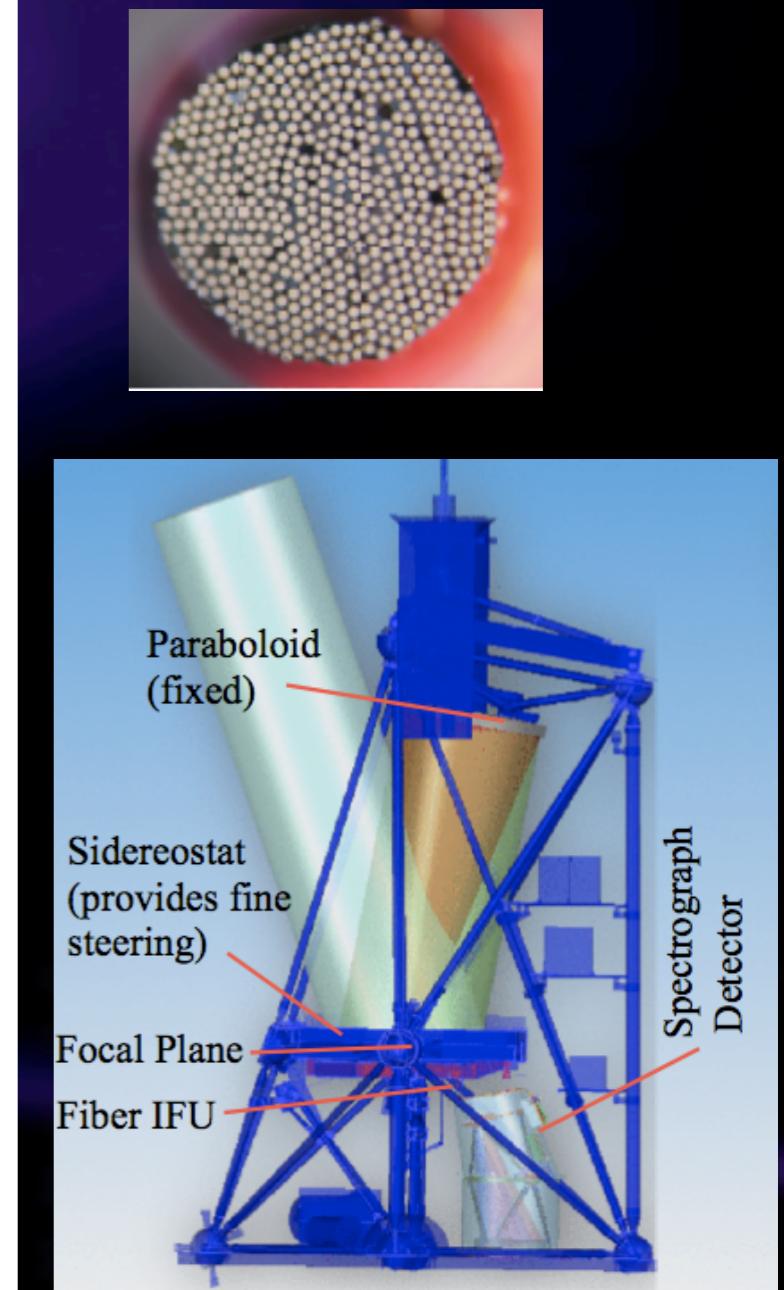
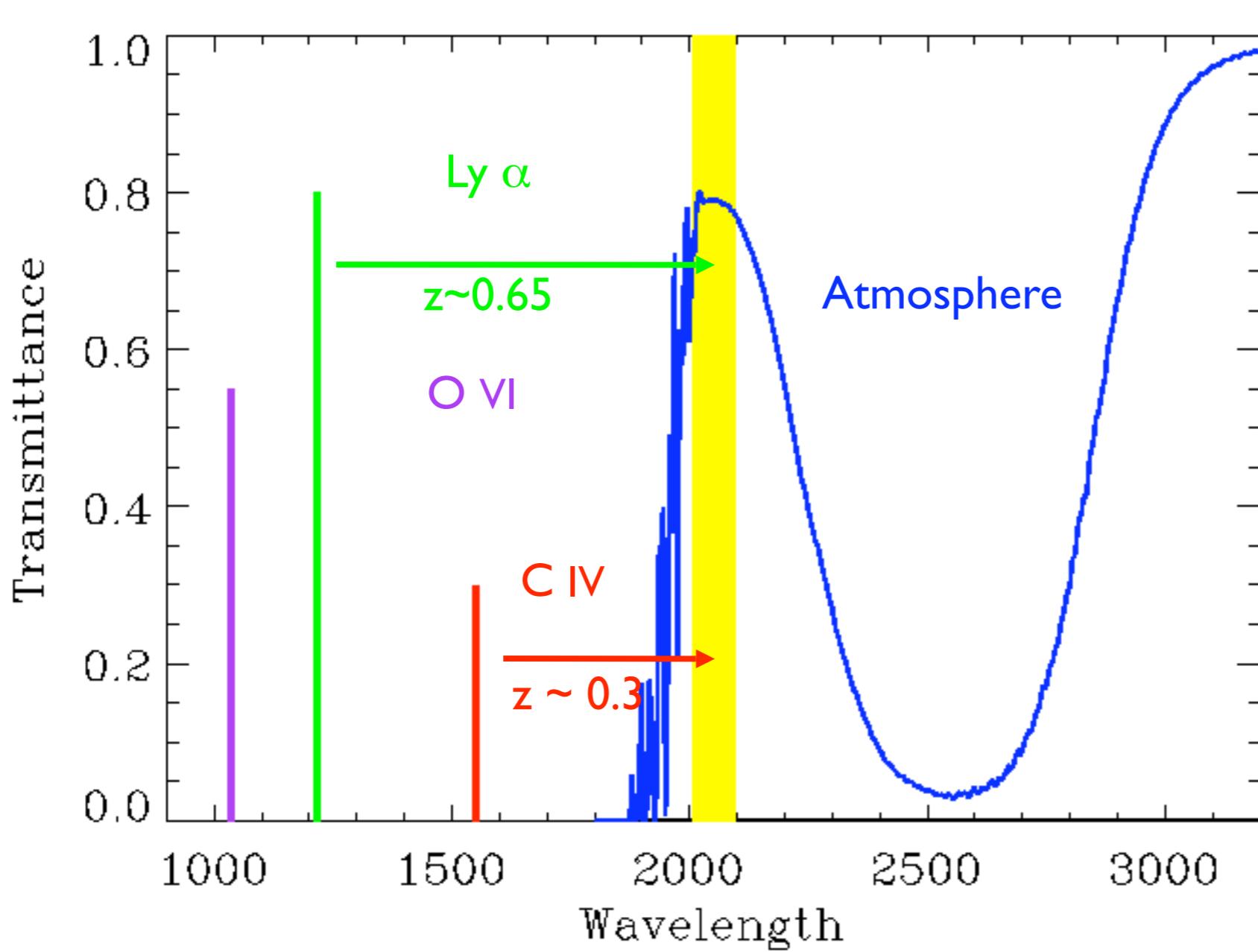
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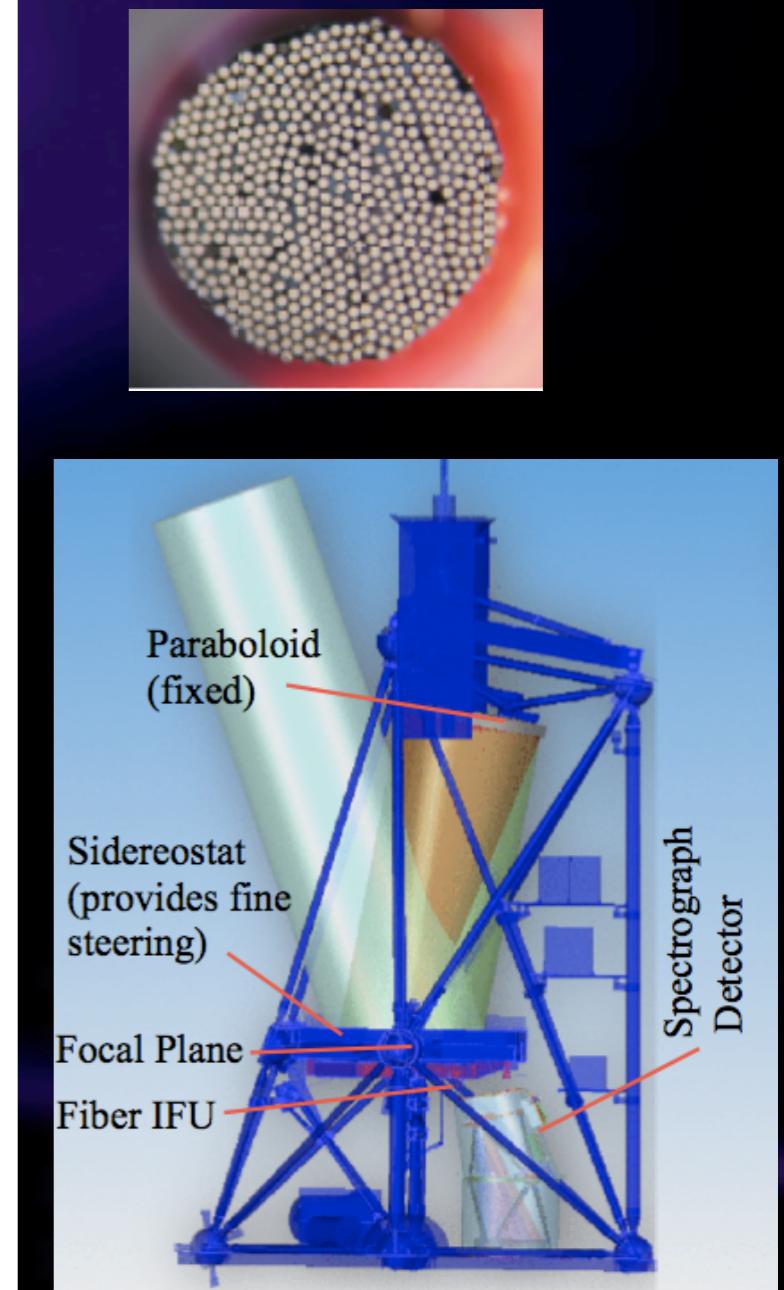
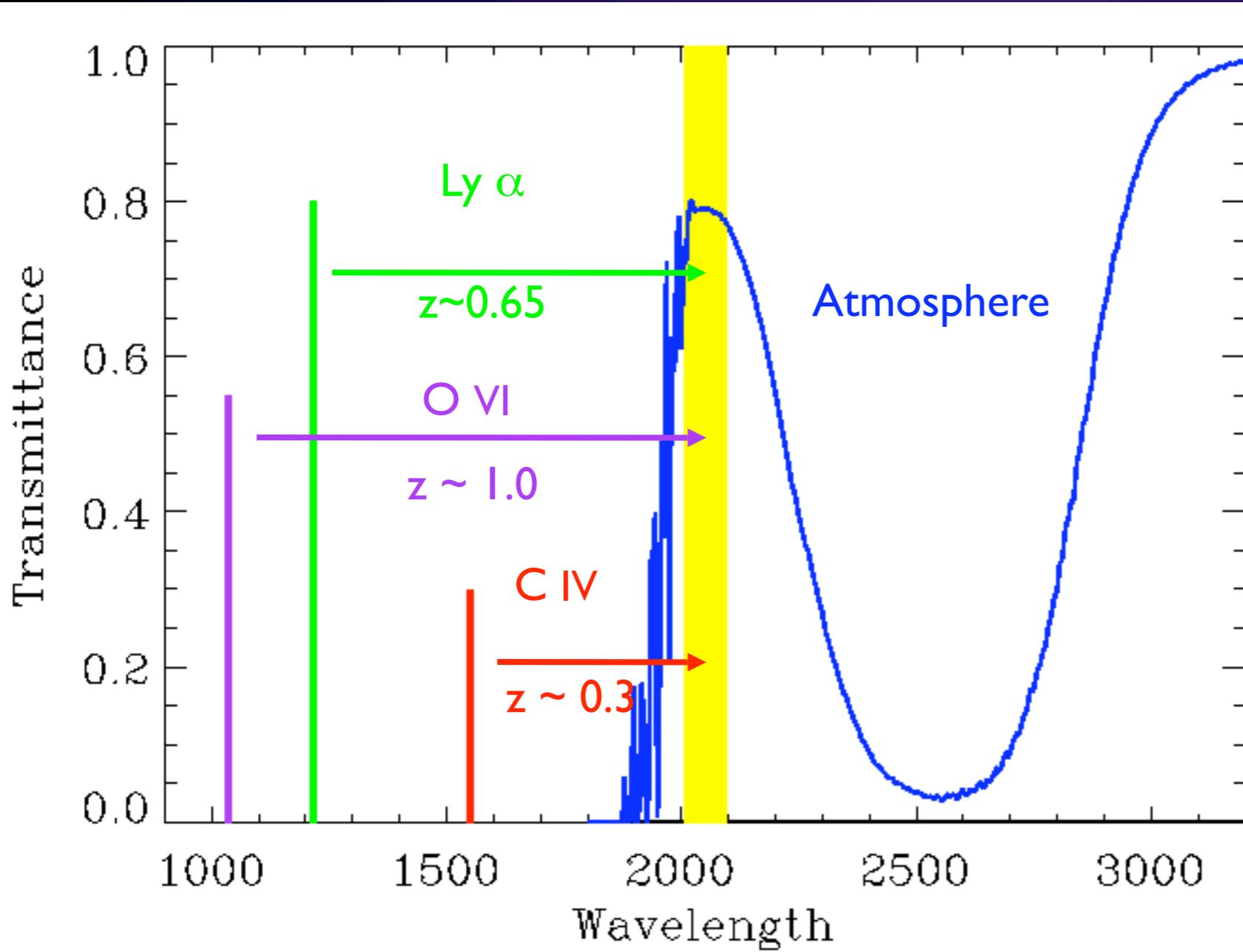
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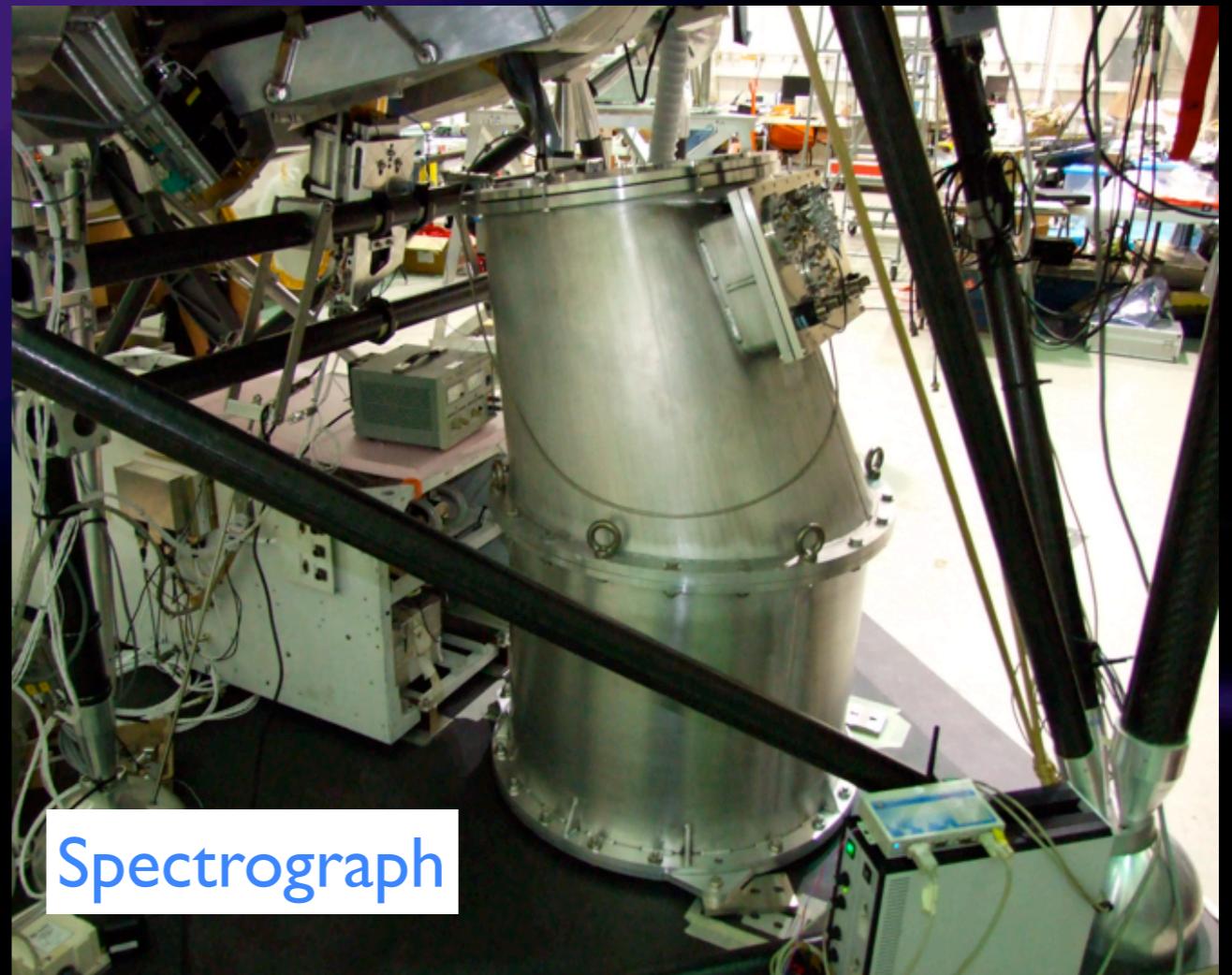
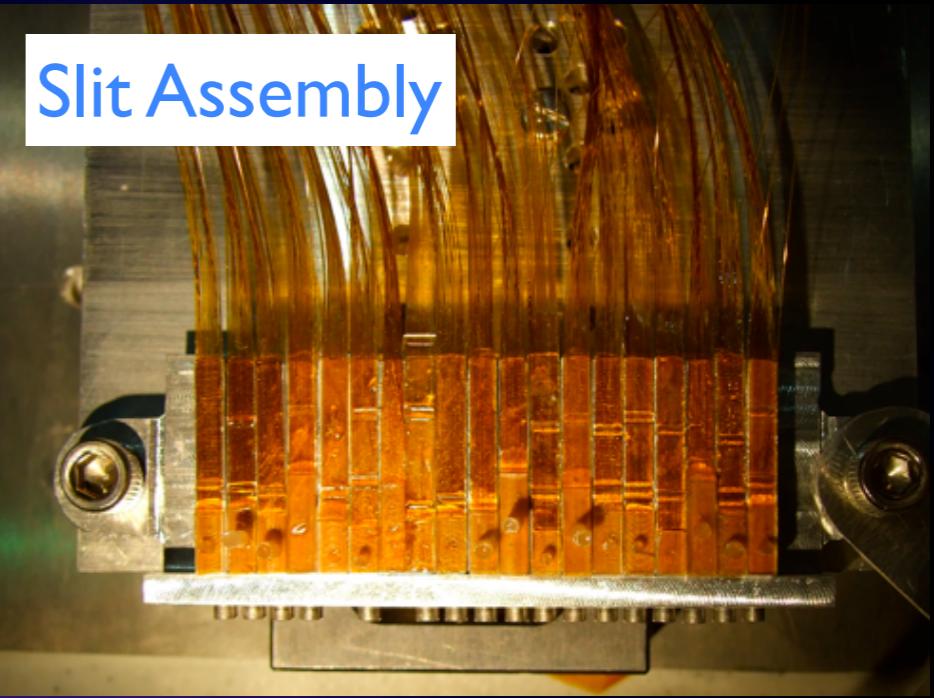
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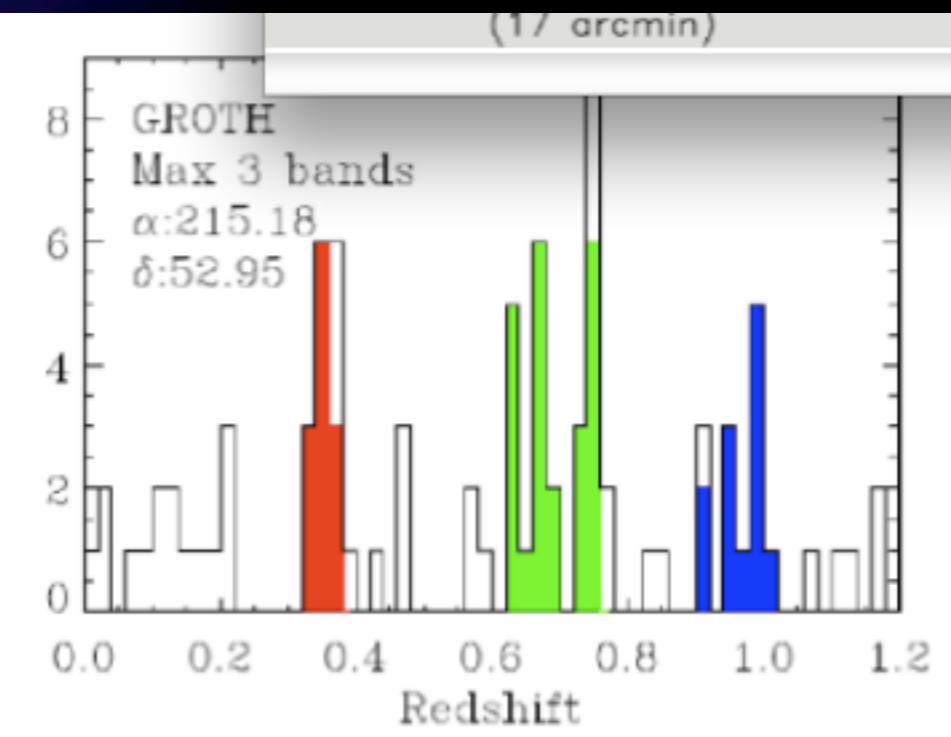
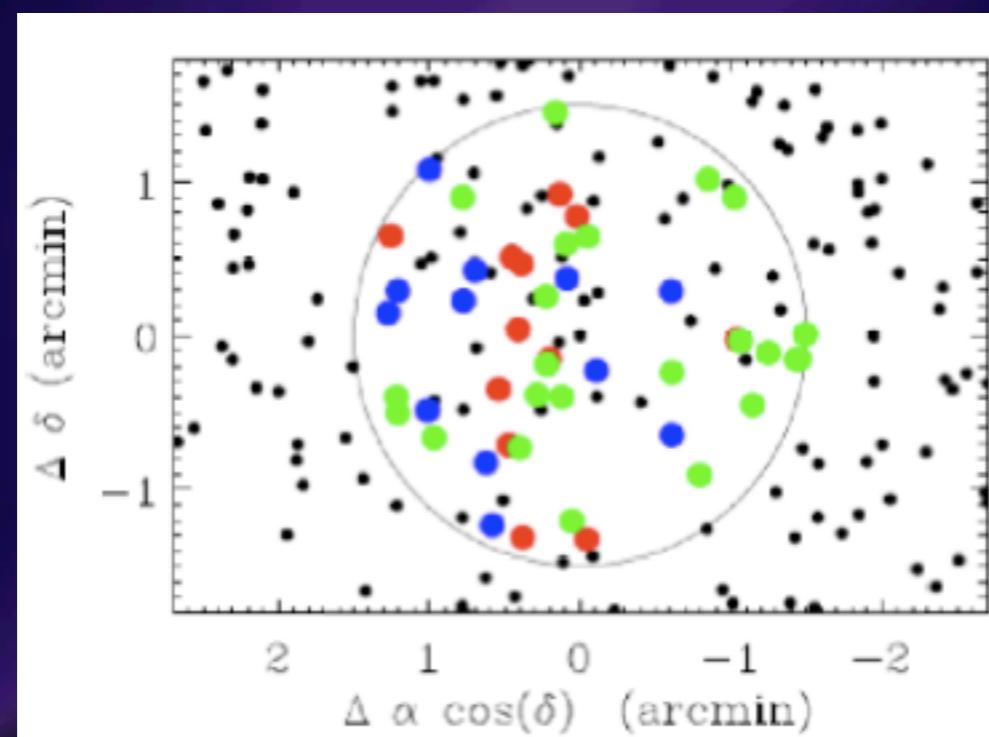
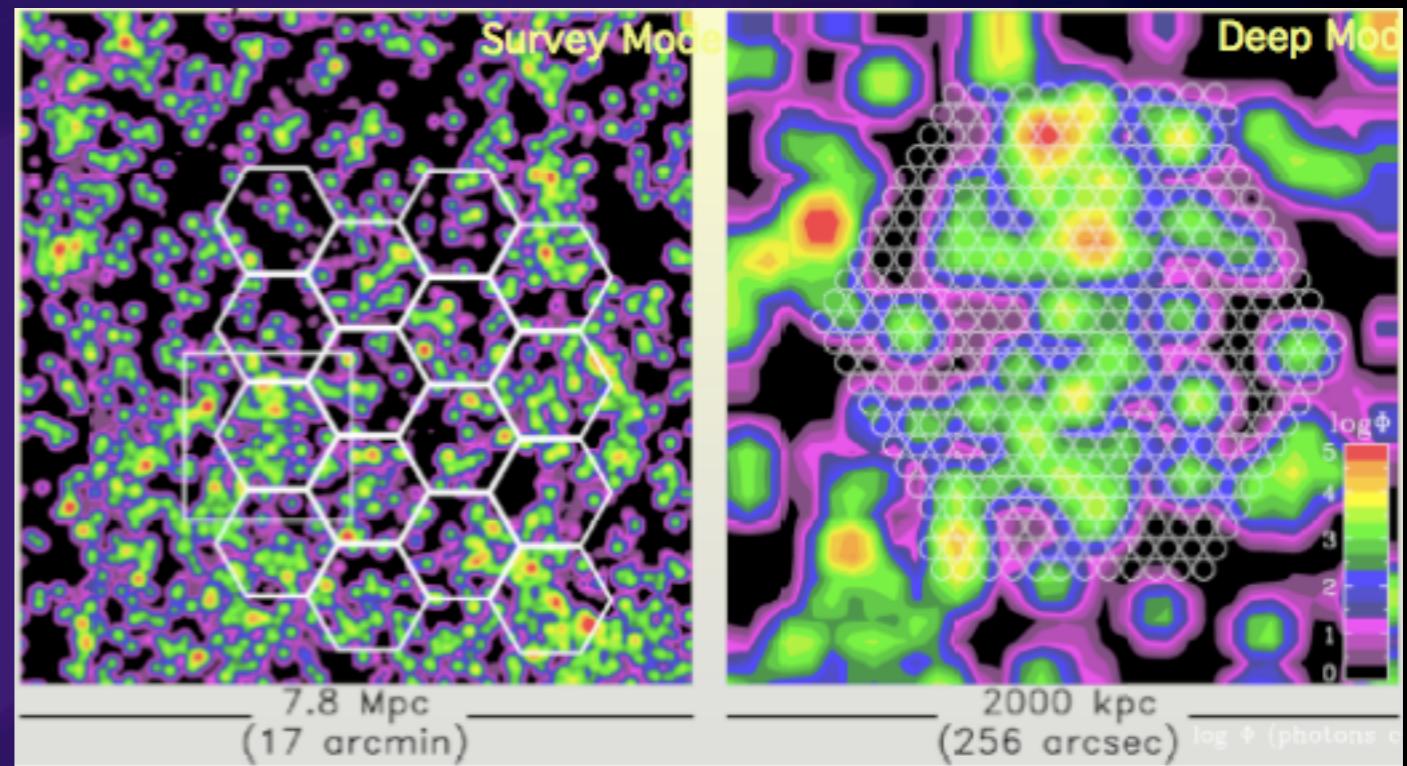
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First Engineering Flight:
Palestine, TX - July 2007

Next flight: Spring 2009



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ISTOS

Imaging Spectroscopic Telescope for Origins Surveys

Revealing the Hidden Cosmic Web of Baryons

CALTECH

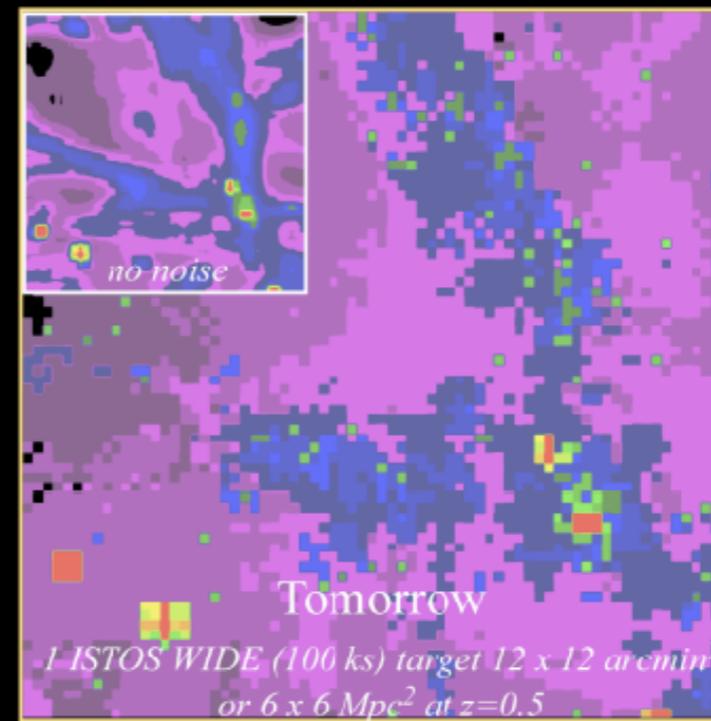
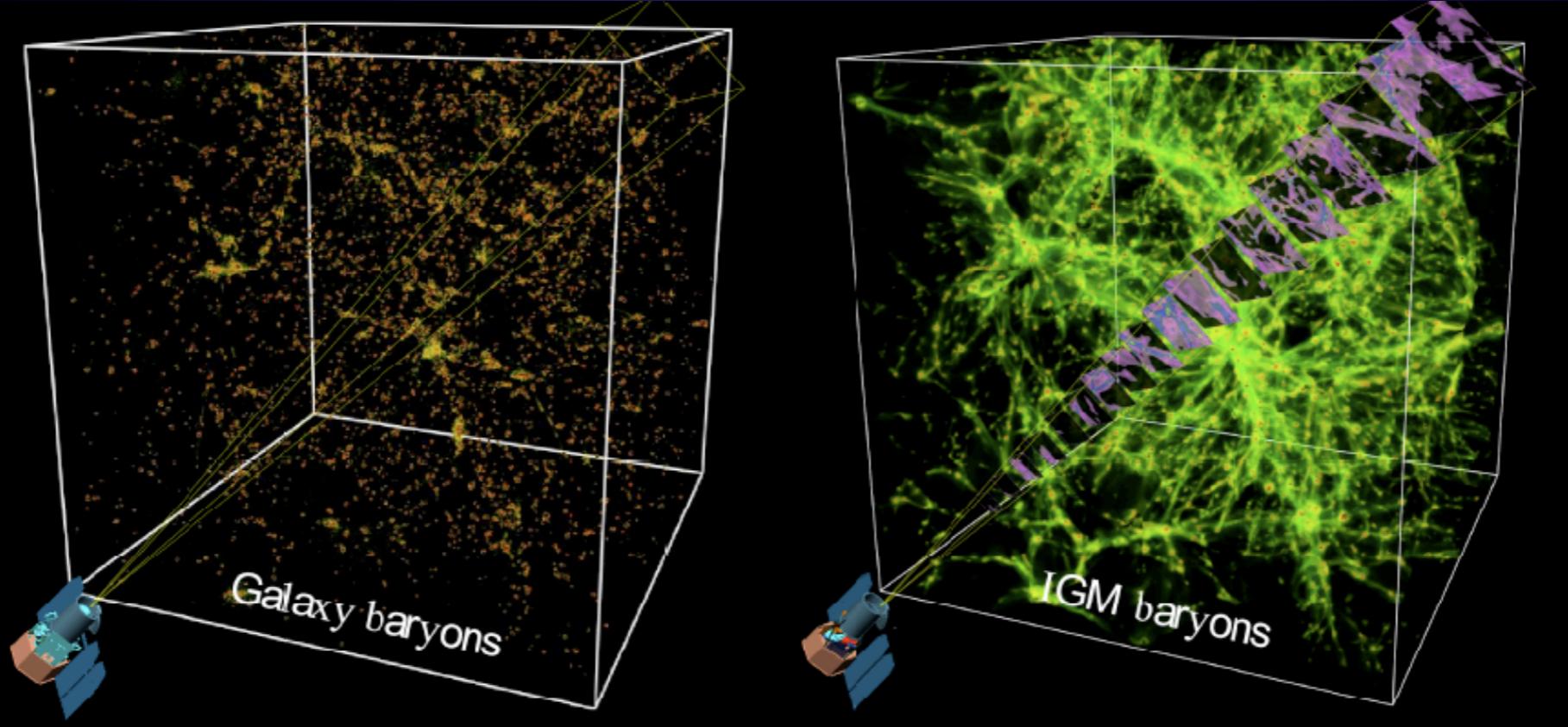


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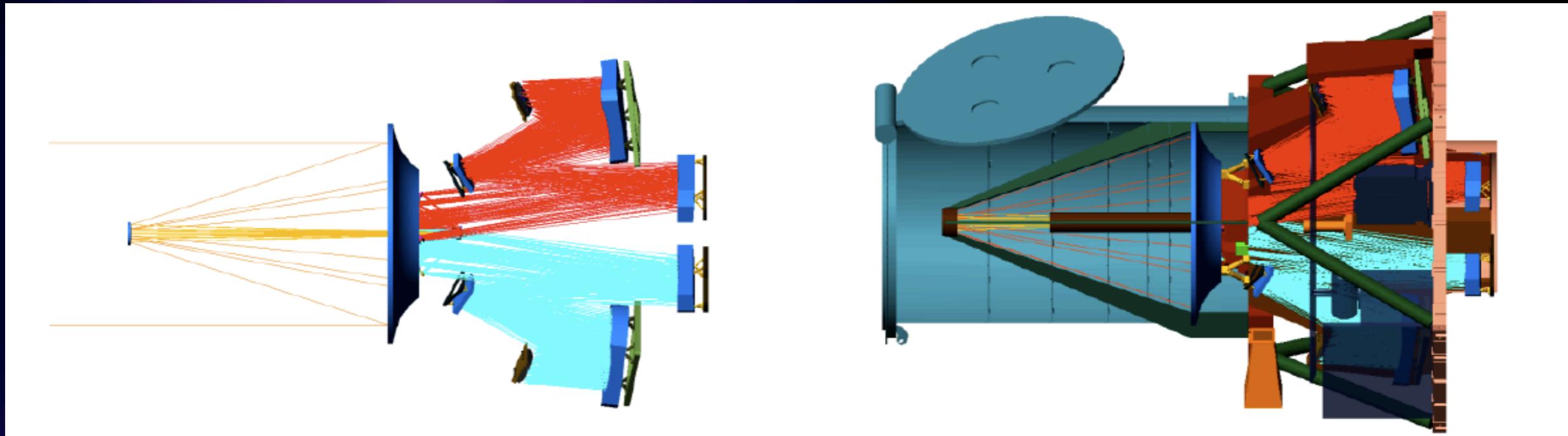
ISTOS

Imaging Spectroscopic Telescope for Origins Surveys

Revealing the Hidden Cosmic Web of Baryons

Goals

- Discover & map IGM emission from the hidden baryons in the Universe
- Discover & map Circum-galactic medium to explore IGM-galaxy co-evolution
- Decode the star formation laws at low and high redshift
- Explore the extended, low surface brightness UV Universe



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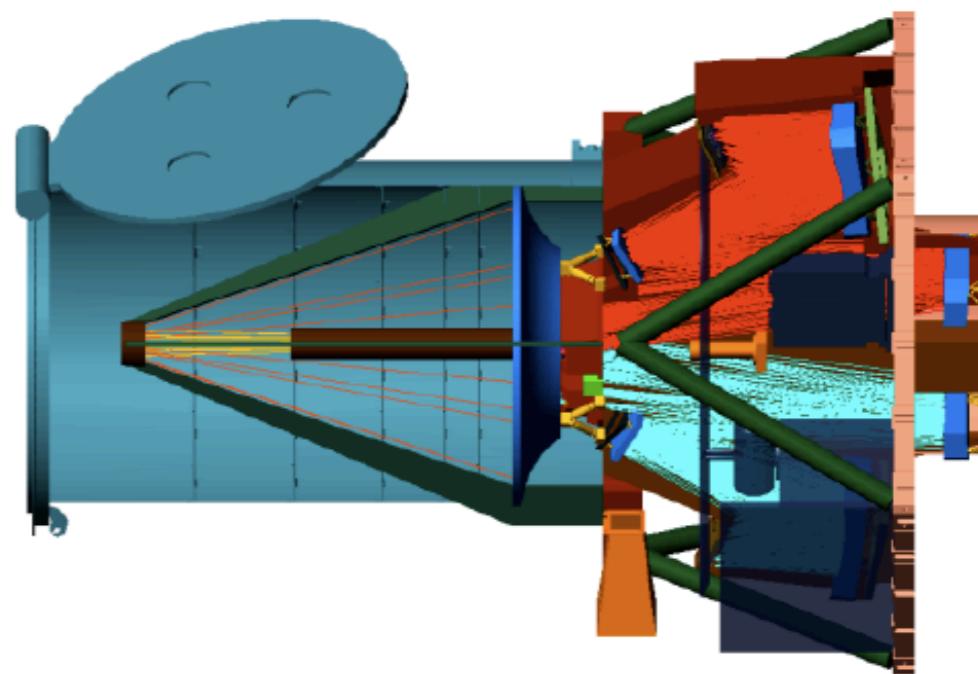
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Design

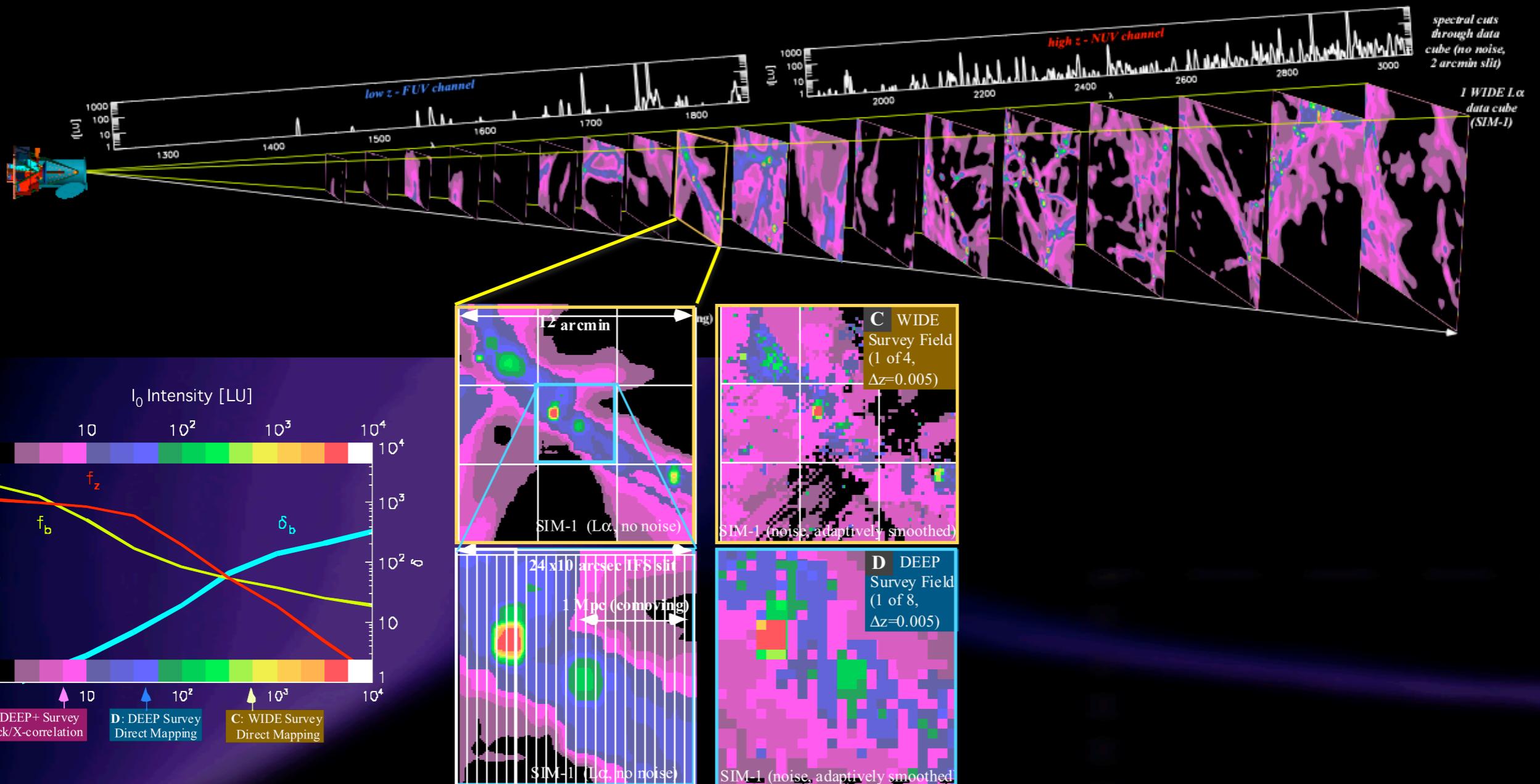
- ✓ 50 cm f/16 Ritchey-Chrétien telescope
- ✓ Dual integral field spectrometer (FUV & NUV),
1250-2800Å bandpass, R~2000
- ✓ 5-10 arcsec spaxels
- ✓ High etendue, 3D mapping of large cosmic
volume of redshifted IGM lines (Ly α , OVI, CIV)
over major period of cosmic evolution
- ✓ High efficiency, low background detectors
- ✓ Extensive GALEX heritage in instrument,
spacecraft, mission design



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Goal I – Discover & Map the Hidden Baryons

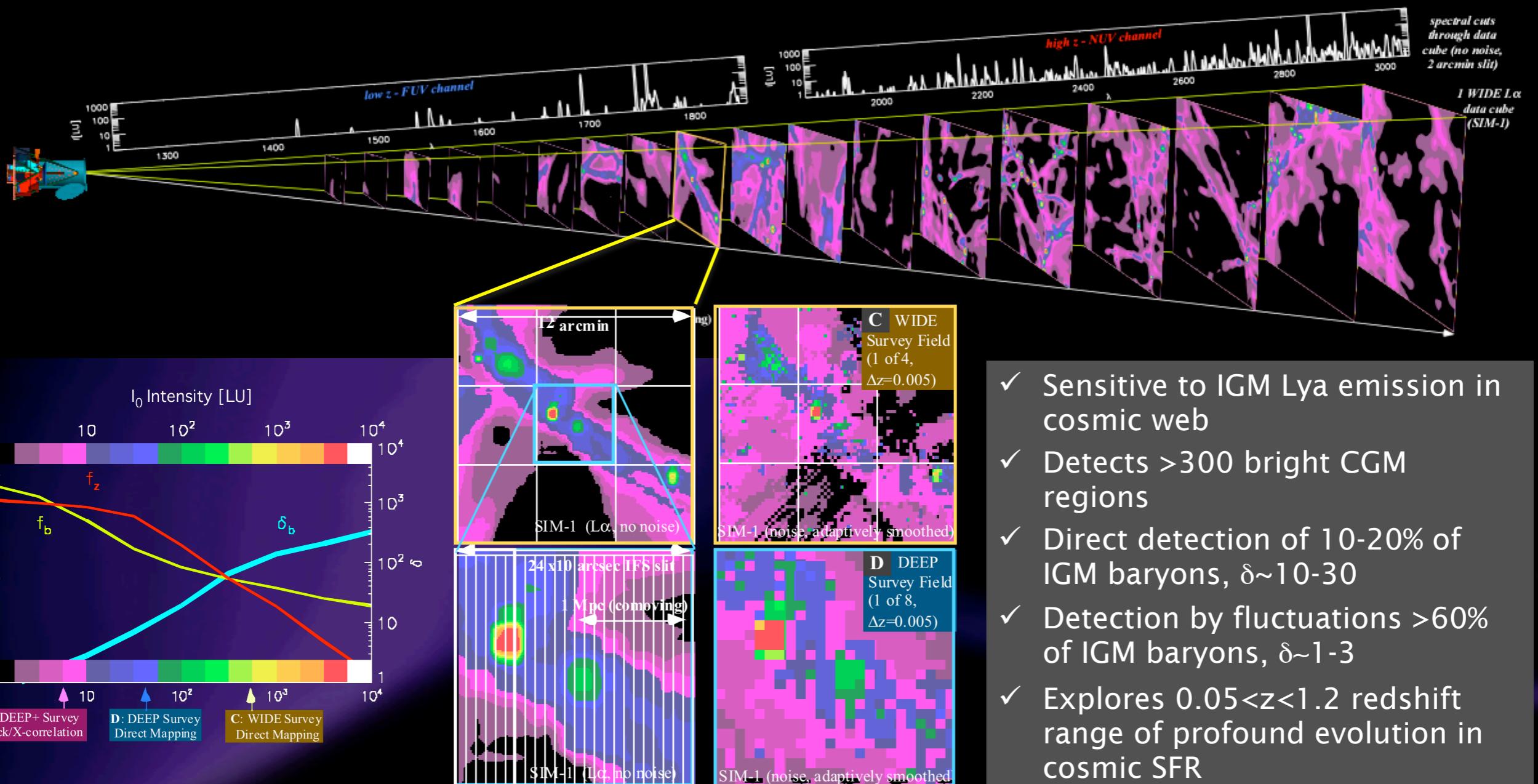
Mapping IGM Baryons over $0.05 < z < 1.2$ with Ly α



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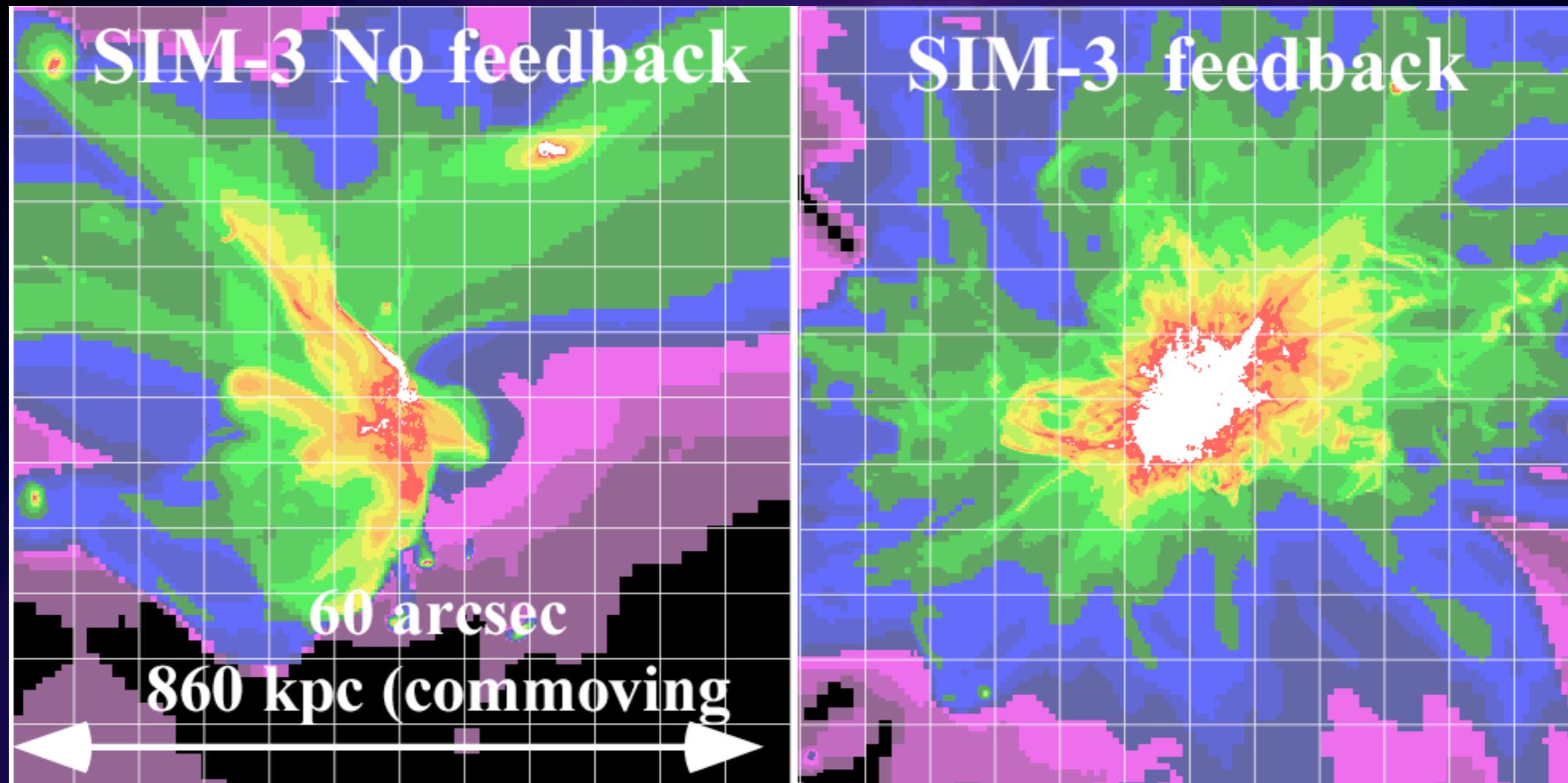
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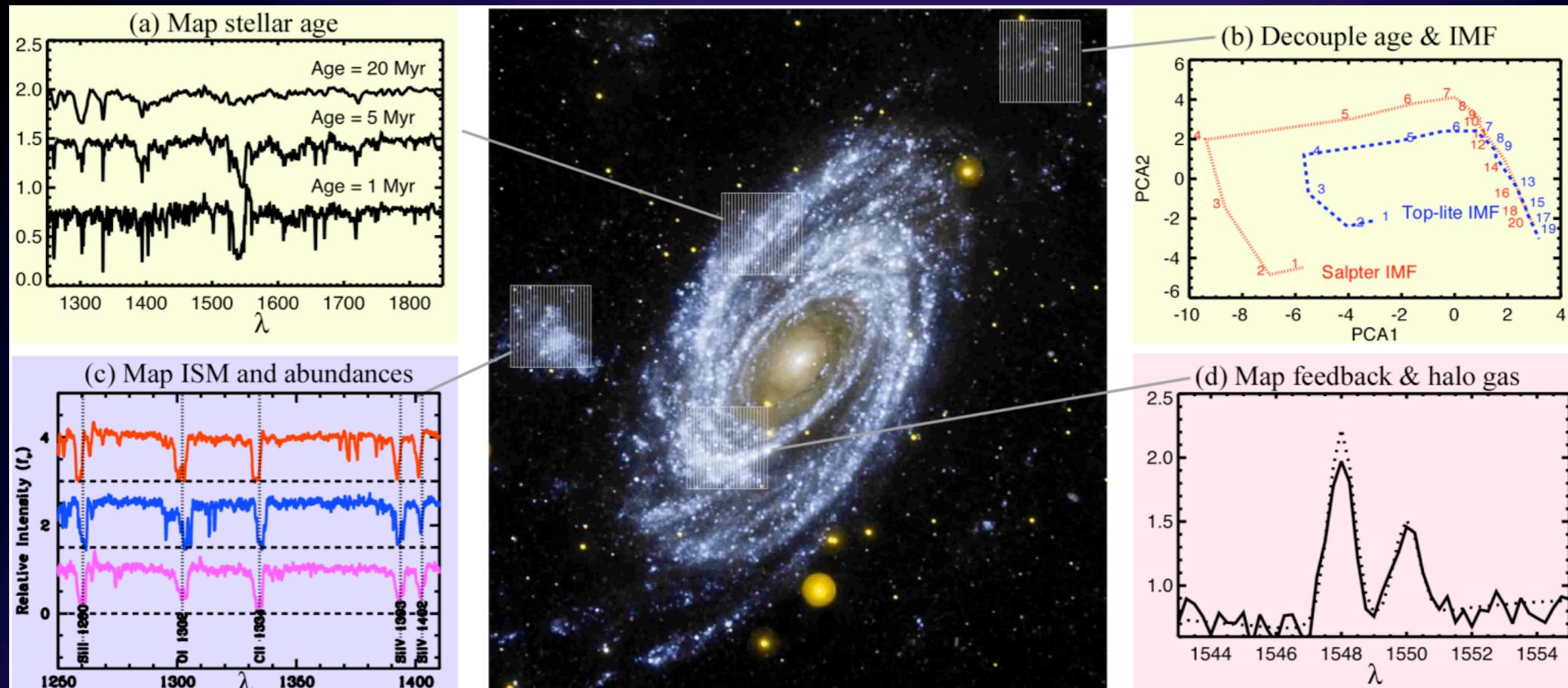
Goal 2 – Discover & Map the Circumgalactic Medium Explore Galaxy-IGM Co-evolution



	SIM-1	SIM-2	SIM-3
Co-I	Cen	Schaye	Bryan
Method	Eulerian grid	Smoothed Particle Hydro	Adaptive Mesh Re-refinement
Feedback	YES	YES	YES
Size	110 Mpc	130 Mpc	1 Mpc
Grid/# part.	Grid 1024^3	$\# 512^3$	$\# 10^6$
Mass resol.	$4 \times 10^8 M_{\odot}$	$10^8 M_{\odot}$	$10^6 M_{\odot}$
Space resol.	100 kpc	3 kpc	0.3 kpc
Ionization	NLTE	LTE	LTE
Emission	CLOUDY	CLOUDY	CLOUDY

ISTOS

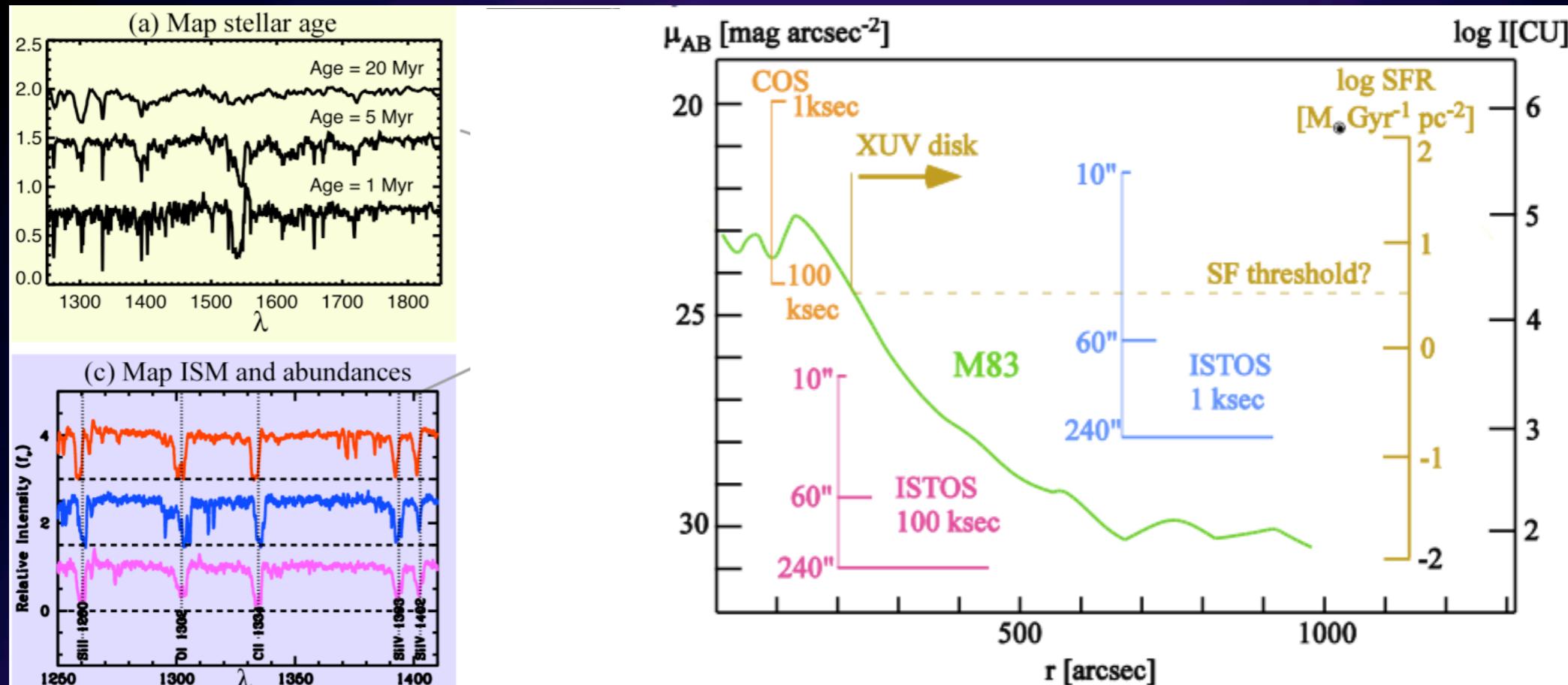
Goal 3 – Understand SF Laws, Feedback Integral Field Spectroscopy of Nearby Galaxies



ISTOS maps <i>ISM gas</i> with these diagnostic lines		ISTOS maps <i>feedback</i> with these diagnostic lines	
Ly limit <912*	Escape of ionizing photons	$\text{Ly}\alpha$ 1216**	Outflow kinematics
Ly series 912-1025*	HI column density, covering fraction	Ly series*	Mass flux
$\text{Ly}\alpha$ 1216**	Kinematics of outflows, CGM gas	OVI1033 [#]	Shocked gas in outflows
FeII 2586/2600	Strong ISM, kinematics	CIV1549	Cooling, shocked gas in halos, SNRs
MgII 2896/2803	Strong ISM, kinematics	FeII, MgII	Outflow kinematics
CII 1334/1335	ISM density/UV radiation field	ISTOS maps <i>abundances</i> with these diagnostic lines	
SiII 1526/1533	ISM density	NV, SiIV, CIV	N, Si, C abundances
H ₂ Lyman bands	ISM density/UV radiation field/dust	OI 1302	[O/H] if HI is measured
ISTOS maps <i>IMF and Age</i> with these diagnostic lines		FeII 1608	[Fe/H]
NV 1238/1242	P-Cygni	FeIII 1935-2020	[Fe/H]
SiIV 1393/1402	P-Cygni	SII 1253, 1259	Fe-peak abundances (not depleted)
CIV 1548/1550	P-Cygni	many weak lines	N, Mg, S, P, Mn, Fe, Ni

ISTOS

Goal 3 – Understand SF Laws, Feedback Integral Field Spectroscopy of Nearby Galaxies



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Summary & Conclusions:

- Physically motivated, high fidelity simulations now predict structured UV emission signatures from WHIM
- “Current instrumentation can detect these features”
 - FIREBall, ISTOS, other concepts, possibly even GALEX
 - Recent improvements in detector QE, noise, and design of nebular spectrographs optimized for detecting WHIM structures
- Detectable Ly α , C IV and OVI emission may trace only a fraction (10-50%) of WHIM component but this phase is extremely useful for understanding how gas flows into and out of galaxies (circumgalactic flows).

GALEX L α from CGM
Stacked UV Luminous galaxies
Matuszewski et al, in prep

